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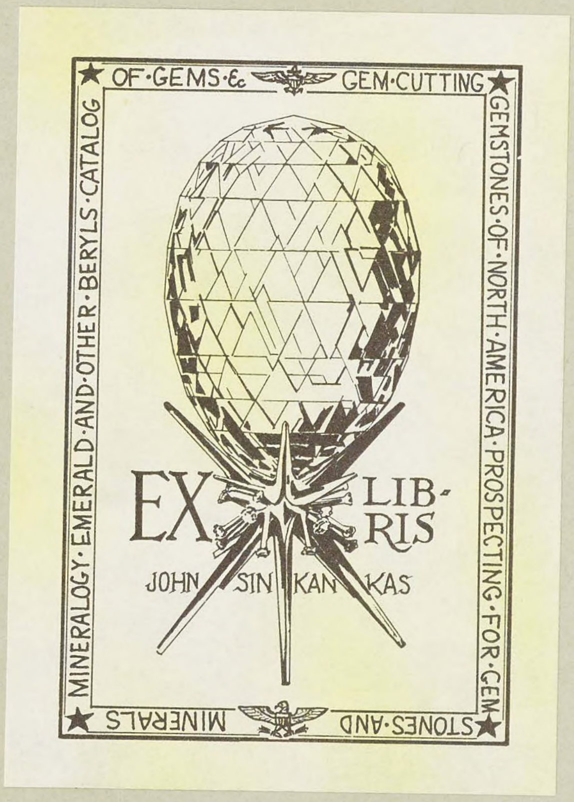
[From The American Journal of Science, Vol. XL, October, 1915]

On AVENTURINE FELDSPAR.

By Olaf Andersen.

With Plates I–III.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ART. XXVIII.—*On Aventurine Feldspar*; by OLAF ANDERSEN. With Plates I–III.

CONTENTS.

INTRODUCTION.

DIFFERENT varieties of feldspar show a more or less distinct metallic schiller, aventurization (sunstone schiller), when light rays fall in certain directions on cleavage faces or artificially polished faces. This schiller is caused by oriented lamellar inclusions which reflect the light with great intensity. The "fire" of the schiller is due to the brilliant interference colors produced by the thin film action of the reflecting lamellæ.

Aventurization may be defined as a play of light and colors caused by strong reflections from thin oriented lamellæ of visible size included in the feldspar.

The terms aventurine feldspar and sunstone have been used interchangeably by previous authors. It seems advisable to

make some distinction between them by using aventurine feldspar as the general term, embracing all feldspars which show aventurization, without regard to the intensity of the phenomenon. Sunstone should then be the special term for those varieties which have intense aventurization and therefore sometimes find use as gem stones.

Aventurine feldspars (sunstones) should be sharply distinguished from the other group of color-playing feldspars known as moonstones, murchisonites and labradorites. These feldspars are characterized by a rather subdued, generally bluish or greenish play of colors ("glaukisiren"*) which is not caused by any visible lamellæ but perhaps by submicroscopic inclusions. The colors are probably due to scattering of light by particles smaller than the wave length of light,† and can not be explained as ordinary interference colors of thin films.

A survey of the literature shows that the conceptions of the problems connected with aventurine feldspars have been rather diverse. A general treatment of the subject based on thorough examinations of different aventurine feldspars has never been attempted. It, therefore, seemed of considerable interest to subject these problems to a somewhat closer study.

I had at my disposal good material from a number of occurrences. Specimens from Norwegian localities were obtained from the Mineralogical Museum of Kristiania University through the kindness of Professor Dr. W. C. Brögger and Mr. Jacob Schetelig. During visits to some of these localities I have also had the opportunity to collect specimens and to study their occurrences. From American localities I obtained good specimens from U. S. National Museum through the courtesy of Dr. G. P. Merrill and Dr. E. T. Wherry, who placed at my disposal (among other specimens) the entire feldspar collection of Isaac Lea, containing the type specimens for the paper referred to below.

PREVIOUS WORK.‡

Aventurine feldspars or sunstones are mentioned in some of the earliest systematic works on mineralogy,§ in which they are described as varieties of feldspars without explanation of the aventurization.

* C. Viola, Zs. Kryst., xxxiv, 171, 1901.

† Cf. explanation of the blue of the sky, C. Viola, loc. cit., p. 188.

‡ The following review is not intended to be complete, the most important work only being mentioned. Some additional references will be found in different parts of the present paper.

§ e. g. Delametherie, Théorie de la Terre, vol. II, p. 201, 1797, where the term heliolithe is used.

R. Jameson, A System of Mineralogy, 1820, vol. II, p. 17, where aventurine feldspars from The White Sea and Archangel are mentioned.

Very little was known about the exact localities or the mineral associations of the sunstones. The first description of an occurrence was given by K. G. Fiedler,* who discovered a locality near Werchne Udinsk, Siberia. Fiedler does not describe the feldspar and the explanation of the aventurization is disposed of in the following remarks: "Ueber diesen Feldspath ist noch zu bemerken, dasz er seinen Goldschimmer der Vulkanität verdankt in welcher er entstand."

The well known occurrence at Tvedestrand, Norway, was discovered by Weiby in 1844. This locality has furnished a large quantity of good specimens, the first of which were carefully examined by Th. Scheerer,† who analyzed the feldspar (oligoclase) and described and gave drawings of the reflecting inclusions, which he determined as hematite. He found these inclusions to be oriented parallel to (001), (010), ($\bar{2}$21) and a vertical prism and summarized his explanation of the origin of the sunstone as follows:‡ "Man musz also annehmen, dasz Oligoklas und Eisenglanz die Producte eines gleichzeitigen Krystallizationsactes sind, und dasz beide, in ihrer regelmässigen Werwachsung ein dem Schriftgranite ähnliches Gemenge darstellen."

A. Kenngott§ discussed the qualities of the reflecting lamellæ, and concluded that they were goethite ("pyrrhosiderit").

E. Reusch‖ discussed, in connection with a careful study of moonstones, the problem of reflections and refractions in bodies like sunstones and moonstones and made a few observations on sunstone from Tvedestrand, correcting and supplementing some of Scheerer's measurements.

Isaac Lea¶ made microscopic examinations of sunstones from different (mostly American) localities and described the reflecting inclusions, which were considered goethite, but did not attempt to determine their orientation, thinking that "they usually lie parallel with the principal cleavage of the feldspar."**

A. Schrauf†† studied aventurization on labradorites and also examined the inclusions in sunstone from Tvedestrand. It was shown that the inclusions from the sunstone were identical with those found in carnallite, the latter determined to be hematite. The lamellæ causing aventurization on (010) of certain labradorites (which also showed labradorization) were found to be oriented approximately parallel to (180) and (170).

J. W. Judd,‡‡ in discussions on the schiller of minerals,

* Pogg. Ann., xlvi, 189, 1839.
† Pogg. Ann., lxiv, 153, 1845.
‡ Loc. cit., p. 161.
§ Sitz.-Ber. Akad. Wien, x, 179, 1853.
‖ Pogg. Ann., cxvi, 396, 1862.
¶ Proc. Acad. Nat. Sc. Philad., 1866, 110.
** Loc. cit., p. 111.
†† Sitz.-Ber. math. naturw. Cl. Ak. Wien, lx, I, 1024, 1869.
‡‡ Quart. Journ. Geol. Soc., xli, 374, 1885. Min. Mag., vii, No. 33, 81, 1886.

embracing aventurine feldspars, came to the following conclusion concerning the origin of the inclusions:* "These enclosures are of the nature of negative crystals which are more or less completely filled with products of decomposition of the mineral." Judd considered these products of decomposition as chiefly consisting of amorphous hydrates of silica and ferric oxide.

H. Tertsch† examined the sunstone from Tvedestrand and found the reflecting lamellæ oriented parallel to (538) and (417), which forms were considered boundary positions ("Grenzlagen") of the simpler form (213).

A. Johnsen determined the inclusions in carnallite‡ and cancrinite§ as hematite, and found them identical with those contained in aventurine feldspars. The presence of the inclusions in carnallite and cancrinite was explained as due to secondary reactions and unmixing in the solid state. It was intimated that the inclusions in aventurine feldspars might be explained in the same way.

I. METHODS OF EXAMINATION AND GENERAL RESULTS.

The study of the specimens embraced three groups of examinations:

(1) Microscopic examinations with the object of determining the feldspars.

(2) Determination of the orientation of the reflecting lamellæ.

(3) Examination of the properties of the reflecting lamellæ.

The results of the first group will be given in the section in which the specimens are described and details of all measurements are given. The present section contains a brief review of the general results of the last two groups in connection with descriptions of the methods applied and discussions of the simple optical problems involved.

Determination of the Orientation of the Lamellæ.

For a complete determination of the orientation of the lamellæ we must know both the coördinates of the different planes parallel to which the lamellæ are oriented and the directions of certain edges of the lamellæ. All orientation must be referred to some crystallographic planes or axes of the feldspar.

* Quart. Journ. Geol. Soc., xli, 384, 1885.
† Tsch. Min. Petr. Mitt., xxi, 248, 1902.
‡ Centralbl. Min., 1909, 168. § Centralbl. Min., 1911, 369.

Planes of Orientation.

As the specimens consisted of cleavage pieces, in general showing no other faces than the cleavage faces (001) and (010), all measurements had to be referred to the elements (001) (010) and the a-axis.

In determining the planes of orientation of the lamellæ we have thus to deal with the following angle coördinates:

ρ_P = angle between P (001) and lamellæ.
ρ_M = angle between M (010) and lamellæ.
ϕ_P = angle between line of intersection : lamellæ $\wedge$ P (001) and a-axis.
ϕ_M = angle between line of intersection : lamellæ $\wedge$ M (010) and a-axis.

A combination of two of these angles determines the plane of orientation of a set of lamellæ.

To be able to refer the measurements to the proper octants in the axial system of the feldspar we must know the approximate direction of the c-axis (or the direction of the positive or negative a-axis) for each cleavage piece examined. In the plagioclases the difference between the obtuse and the acute edges of the a-axis must also be noticed. On specimens of microcline the perthite striation on (010) will generally indicate the approximate direction of the c-axis. In the plagioclases it is necessary to look for indications of the third cleavage, parallel to $(1\bar{1}0)$, or else to rely on the determination of extinction directions on small cleavage pieces chipped off from the larger.

The angles ϕ could be measured either with the microscope on oriented sections after (001) and (010), or with the goniometer on cleavage pieces. The angles ρ were always measured with the goniometer.

Measurements with the microscope.

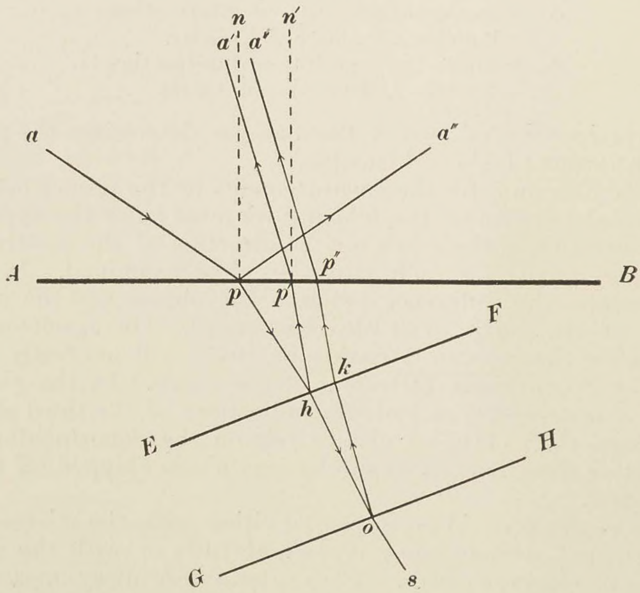
The measurements of the angles ϕ on thin sections consisted in determining the angle between the cleavage lines and the lines of intersection of the lamellæ with the surface of the section. The latter lines we will call the section lines of the lamellæ.

As there were always more than one set of lamellæ to be measured, the difficulty in determining the orientation of each set by measuring the two angles ϕ would consist in a correct correlation of the measurements from the two different sections. For each set, the angle ϕ of which had been determined in one section, it was necessary to estimate the angle ρ in the same section in order to get an idea of the orientation of the

lamellæ in space. It was then possible to identify the same set of lamellæ in the second section on which the other angle ϕ was to be determined.

A more detailed description of the microscopic measurements is unnecessary, especially since the method was only used in the preliminary work and in cases where the angles ρ of the lamellæ were too large to be measured with the goniometer.

Fig. 1.



Some of the measurements will be recorded in connection with the description of the specimens.

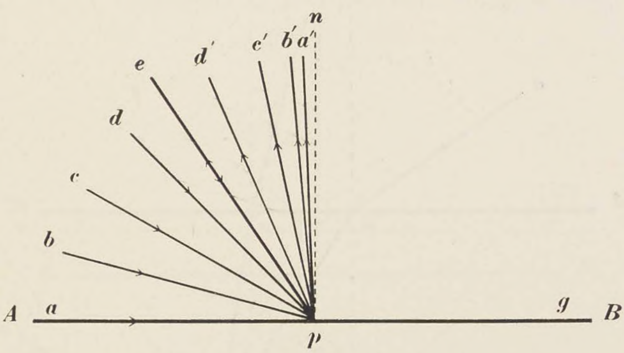
Remarks on the Optics of Aventurine Feldspars.

Before describing the measurements with the goniometer a brief general discussion of the course of light rays in aventurine feldspars will be in place. We consider only rays in the main reflection plane, the plane perpendicular to the section lines of the lamellæ, as only such rays are used in the measurements.

In fig. 1, *A B* represents the surface of a cleavage piece containing a reflecting lamella *E F G H*. The plane of the drawing is perpendicular to the section line of the lamella. The lamella, drawn at an angle ρ of approximately 21°, has

the actual position of the main set of lamellæ that cause the aventurization on (001) of the feldspars. The rays are constructed at the approximately true angles obtaining in an oligoclase (n = 1·54). A very high refractive index (n = about 3) is assumed for the construction of the rays inside the lamella. In the discussions we disregard (as we do in the figures) the double refraction of the feldspar, and also an eventual double refraction of the lamellæ. This will simplify the problems very considerably without changing their general character.

FIG. 2.



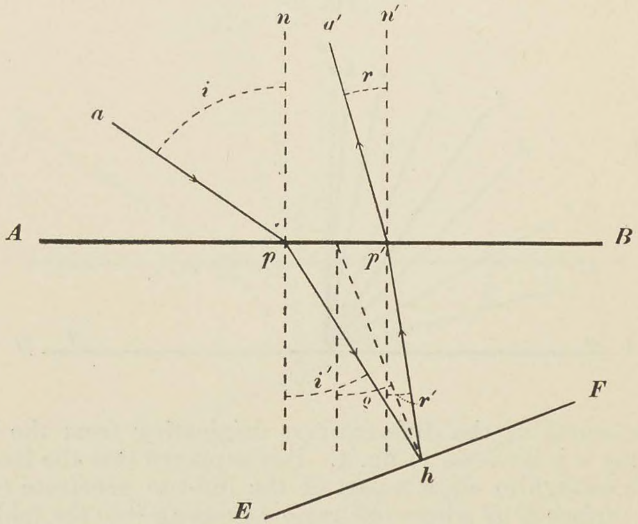
The course of the different rays originating from the incident ray $a\ p$ is shown in fig. 1. It is supposed that the lamella is thin enough to allow a part of the light to penetrate to its lower surface $G\ H$ where one ray $o\ s$ proceeds into the feldspar and the other is reflected in the direction $o\ k$. There will then be opportunity for an interference between the two rays $h\ p'$ and $k\ p''$ with a path difference equal to $h\ o\ k$ or approximately the double thickness of the lamella (as the angle $h\ o\ k$ is always very small). In white light we will, therefore, see interference colors in the direction $p'\ a'$ ($p''\ a''$) of the light rays which pass out through the surface $A\ B$.

In the following discussion we use the symbol i for the angle $a\ p\ n$ (fig. 1), the angle of incidence of rays falling on a surface (AB) and the symbol r for the angle $a'\ p'\ n'$, the angle at which the same rays emerge from the same surface after the reflection from the lamellæ.

Fig. 2 shows the relations between the angles i and r for a number of rays constructed on the basis of the same properties as fig. 1. (Feldspar with n = 1·54; lamellæ with angle ρ = 21°.) The angles i and r will differ somewhat for different aventurine feldspars and will especially depend on the angles

ρ. As will be shown further on, however, all the lamellæ that cause aventurization on (001) have practically the same angle ρ_P (about 21°) and those producing aventurization on (010) have an angle ρ_M only a little smaller (around 19°). The differences in the angles i and r will therefore be small. Fig. 2 may then be considered a fair representation of the general relations between the angles i and r in aventurine feldspars where the aventurization is observed on the cleavage faces

Fig. 3.



(001) and (010). The incident rays are marked with small letters and the corresponding reflected rays with the same letters distinguished by prime signs. It is seen that rays $a\ p$ of angle $i = 90°$ are reflected in the direction $p\ a'$ at a very small angle r. For an angle ρ of 21° all the incident and reflected rays fall on the same side of the face normal $p\ n$. For smaller angles ρ they may, in part, fall on opposite sides. The direction $e\ p$ represents the ray which after the refraction at the surface $A\ B$ will coincide with the normal to the reflecting lamellæ. Incident rays along the line $e\ p$ will, therefore, emerge along the same line, that is, the angles i and r for these rays are equal and $e\ p$ represents, in a way, the axis of incidence for the whole reflecting system feldspar-lamellæ. Rays falling on the surface $A\ B$ in any direction between $p\ a'$ and $p\ g$ will not pass out through the same surface after the reflection from the lamellæ, because they will be totally reflected at the surface.

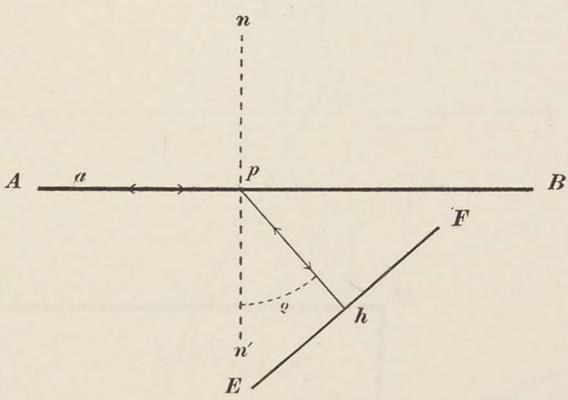
By considering fig. 3 we infer easily how the angle ρ is calculated from the angles i and r of any rays.*

$$\rho = \frac{i' + r'}{2}\ ; \quad \sin i' = \frac{\sin i}{n}\ ; \quad \sin r' = \frac{\sin r}{n}\ ;$$

n is the mean refractive index of the feldspar.

In order that rays falling on a certain surface after the reflection from the lamellæ shall emerge through the same surface, the angle ρ of the lamellæ must not exceed the angle of total reflection for feldspar against air. This is easily seen in fig. 4, which represents a feldspar containing a lamella of

Fig. 4.



angle $\rho = 40°$, approximately the angle of total reflection for oligoclase.

For lamellæ parallel to the surface of the feldspar, the reflected rays will, of course, coincide with the rays reflected directly from the surface. Such lamellæ do not, therefore, produce the same brilliant aventurization as lamellæ of medium angles ρ, because the colored light reflected from the lamellæ will be blurred by the white light reflected directly from the surface of the feldspar.

We may now consider a case where the light rays pass in through one face and after the reflection from the lamellæ pass out through another face. In the case illustrated in fig. 5, AB and AC represent the two cleavage faces (001) and (010) of an oligoclase and EF a lamella oriented parallel to $(0\bar{2}1)$; that is

* See E. Reusch, loc. cit., p. 401, where many of the optical problems are discussed in detail.

the lamella and the two faces of the feldspar lie in the same zone. Rays in the plane perpendicular to the a-axis of the feldspar will, therefore, remain in this plane throughout and the calculations of the relations between the different angles are simple. We find easily the following formulæ :

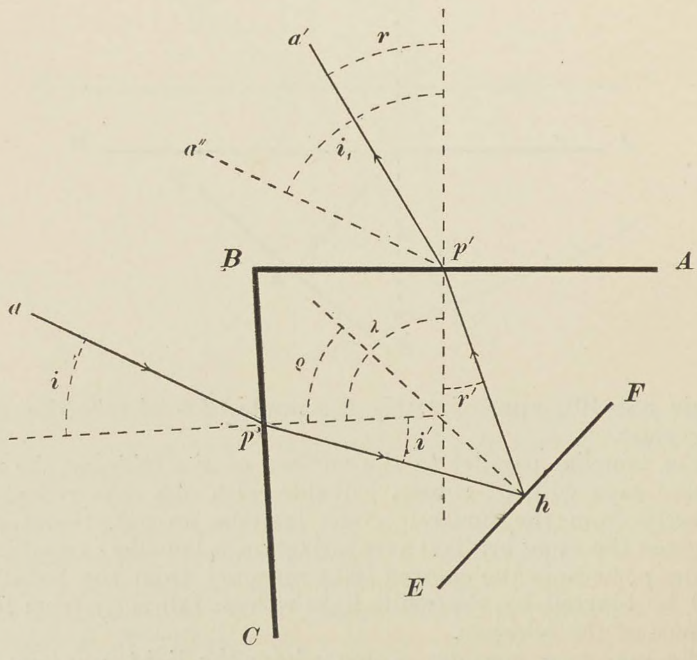
$$\rho = \frac{\lambda + i' - r'}{2}.$$

$$\sin i' = \frac{\sin i}{n}\ ;\ \sin r' = \frac{\sin r}{n}$$

$$i = \lambda - i_1$$

The meanings of the different symbols are indicated in fig. 5.

Fig. 5.

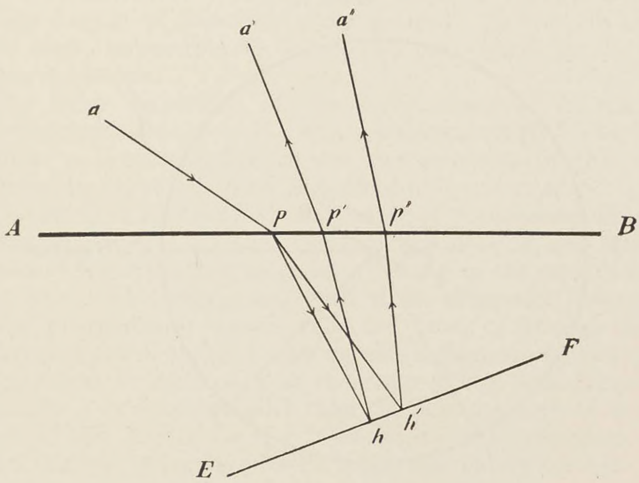


These formulæ enable us to calculate the angle ρ of any set of lamellæ lying in the zone of two faces when the angle λ between the faces is known and the angles i (or i_1) and r of any light ray can be measured.

In the preceding discussion we have, in general, tacitly assumed that the light was homogeneous. In fig. 6 the incident ray $a\,p$ is supposed to consist of white light. After

the refraction at the surface $A\ B$ the red rays follow the course $p\ h'\ p''\ a''$ and the violet rays the course $p\ h\ p'\ a'$. The reflection from the lamellæ of aventurine feldspars will thus, in general, be accompanied by a color dispersion of the light. The magnitude of the dispersion will depend on the angle i of the incident rays, the angle ρ of the lamellæ and the specific power of dispersion of the feldspar. As this power of dispersion is low with feldspars the actual color dispersion in aventurine feldspars will always be insignificant. For lamellæ parallel to the surface ($\rho = 0$) there will be no dispersion.

FIG. 6.



Goniometric Measurements.

For the goniometric measurements cleavage pieces with smooth faces of the forms (001) and (010) and showing distinct aventurization on both faces were selected. The faces generally measured from 2×2^{mm} to 10×10^{mm}.

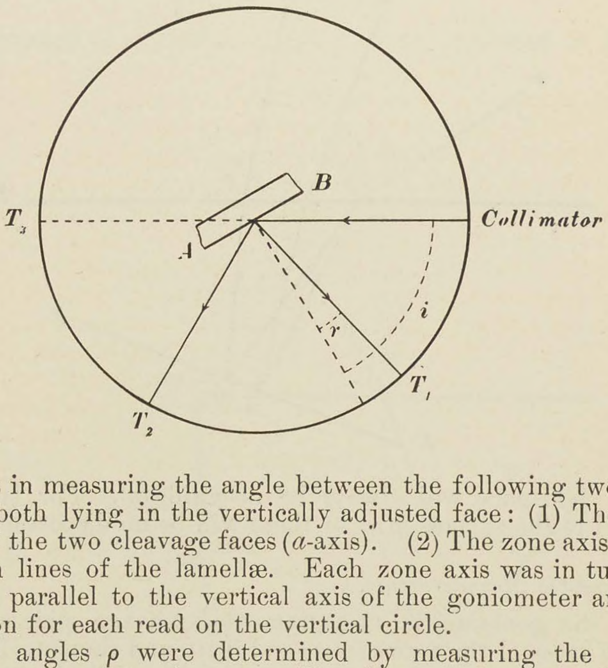
The measurements were made with a Goldschmidt two-circle goniometer in the following way: The cleavage face to be used as equator was first adjusted parallel to the vertical circle of the goniometer. The cleavage piece could then be rotated round the horizontal axis without changing the vertical position of the face.

In cleavage pieces composed of polysynthetic twins the single twinning lamellæ were sometimes broad enough for individual adjustment and contained a sufficient number of

reflecting lamellæ for measurement. As a rule, however, they were too narrow and the whole set of parallel faces had to be adjusted as one face without regard to the intervening twinning faces. By selecting the broadest set this could be done without difficulty and after the adjustment the signals belonging to the adjusted faces could be easily distinguished from signals belonging to the other twinning faces.

The determination of the angle ϕ of any set of lamellæ that reflected light through the adjusted cleavage face would now

Fig. 7.



consist in measuring the angle between the following two zone axes, both lying in the vertically adjusted face: (1) The zone axis of the two cleavage faces (a-axis). (2) The zone axis of the section lines of the lamellæ. Each zone axis was in turn adjusted parallel to the vertical axis of the goniometer and the position for each read on the vertical circle.

The angles ρ were determined by measuring the angles i and r in the following way: The cleavage piece was adjusted with one face parallel to the vertical circle as before, and the section lines of the set of lamellæ to be measured were set parallel to the vertical axis of the goniometer. The vertical cleavage face was then fixed in a position which gave a suitable angle of incidence to the rays from the collimator and readings were made on the horizontal circle with the telescope in the following three positions (see fig. 7):

(1) T_1, position of reflections from lamellæ. (2) T_2, position of direct reflection from the cleavage face. (3) T_3, position of direct signal from the collimator. How the angles i

and r are computed from the readings is easily seen. The formulæ for the calculation of ρ from i and r have been given before (p. 359).

Direct measurements of the angles ρ could be made occasionally when lamellæ were exposed on fracture faces. These measurements were, of course, in no way different from ordinary goniometric angle measurements.

In determining the angles ρ by measuring the angles i and r we should theoretically obtain two values owing to the double refraction of the feldspar. The deviation between these values is, however, always so small as to be negligible even if a high degree of accuracy were desired. It was, in fact, in most cases, impossible to distinguish two signals in the goniometer telescope.

The color dispersion of the light observed in the same measurements (see p. 361) was also insignificant and it was without noticeable influence on the accuracy of the results when white light was used instead of monochromatic.

The relative accuracy of the goniometric measurements will, of course, depend on the variable qualities of the cleavage faces and the reflecting lamellæ. Owing to the poor cleavage faces after (010) compared with those after (001) (especially in the plagioclases) signals reflected from or passing through (001) were much sharper than signals influenced by (010).

It should be noticed that the error in the determination of an angle ρ is much smaller than the actual errors of measurements of the angles i and r from which ρ is calculated, provided that the refractive index is approximately correct. This is plainly inferred from the formulæ p. 359.

We find that the error in the angle determination in general will increase in the order ρ_P, ρ_M, ϕ_P, ϕ_M. In the best determinations of the angles ρ the probable error of single measurements did not exceed that of ordinary goniometric measurements of medium sharpness ($2' - 3'$). In the poorest determinations of the angles ϕ it would reach $1/2°$ or more. (See Tables 2–12.)

In most of the measurements the goniometer telescope was used with a reducing attachment; in a few cases with a lense system of low magnifying power. Each angle value listed in the tables (Tables 2–12) is the average of several (generally 5) readings.

Results of Measurements.

The results of the microscopic and goniometric measurements of the planes of orientation may now be briefly summarized.

It was found that the lamellæ, in all the different varieties examined, were oriented parallel to definite, crystallographic faces of the feldspar, and all these faces had rather simple indices. The lamellæ causing the aventurization on the cleavage faces were oriented along the same crystal faces in all the varieties.

Altogether it was found that the planes of orientation of the lamellæ were parallel to faces of the following forms: (112), $(1\bar{1}2)$, $(\bar{1}13)$, (150), $(1\bar{5}0)$, (110), $(1\bar{1}0$, $(0\bar{2}1)$, (010), (001).

Of these (001), (010), (110) and $(1\bar{1}0)$ are known as actual faces in practically all feldspar crystals; $(0\bar{2}1)$ is also a fairly common form, whereas (112), $(1\bar{1}2)$, $(\bar{1}13)$, (150) and $(1\bar{5}0)$ belong to the very rare forms that have been observed only occasionally and with insignificant faces.

Table 1 gives the angles ρ_P, ρ_M, ϕ_P and ϕ_M of the forms mentioned, for albite, anorthite and orthoclase calculated from the known axial ratios of these minerals.*

For the sake of completeness the angles of the forms $(\bar{1}\bar{1}3)$ and (021) are also given. All the angles are given with positive and acute values. The direction in which the angle should be counted and whether the positive or the negative a-axis should be used as base is always easily inferred.

For comparison with the measurements the calculated angles of the aventurine plagioclases were simply computed by interpolation between the angles of albite and anorthite on the basis of the known compositions of the plagioclases (see Tables 2–8). This method may not be strictly correct, but it is accurate enough for our purpose and, in fact, probably the most accurate method available,† as the axial ratios of the different plagioclases are but imperfectly known.

The angles measured on microclines (microcline perthites) are compared with the calculated angles of orthoclase for the reason that the microcline, as usual, was always so finely twinned that the orientation of the reflecting lamellæ could not be measured in relation to single twinning lamellæ (as in the case

*Albite: $a : b : c = 0{\cdot}6367 : 1 : 0{\cdot}5593$
$\alpha = 94°\ 15'$; $\beta = 116°\ 37'$; $\gamma = 87°\ 41'$.
($\lambda = 86°\ 24'$; $\mu = 63°\ 28'$; $\nu = 90°\ 28'$.)

C. Dreyer und V. Goldschmidt, Meddelelser om Grönland, xxxiv, 1907. (In the table of elements, p. 43, is given $\lambda = 86°\ 42'$ instead of $86°\ 24'$.)

Anorthite: $a : b : c = 0{\cdot}6347 : 1 : 0{\cdot}5501$
$\alpha = 93°\ 13'$; $\beta = 115°\ 56'$; $\gamma = 91°\ 12'$.
($\lambda = 85°\ 50'$; $\mu = 63°\ 56'$; $\nu = 87°\ 6'$).

V. Goldschmidt, Winkeltabellen, (1897, p. 141).

Orthoclase: $a : b : c : = 0{\cdot}6585 : 1 : 0{\cdot}5554$
$\beta = 116°\ 3'$.

V. Goldschmidt, Winkeltabellen (1897, p. 143).

†See V. Goldschmidt, Winkeltabellen (1897, p. 404).

TABLE 1

Form	ALBITE				ANORTHITE				ORTHOCLASE			
	Pole : Normal to 001		Pole : Normal to 010		Pole : Normal to 001		Pole : Normal to 010		Pole : Normal to 001		Pole : Normal to 010	
	ρ_P	ϕ_P	ρ_M	ϕ_M	ρ_P	ϕ_P	ρ_M	ϕ_M	ρ_P	ϕ_P	ρ_M	ϕ_M
112	20° 38′	59° 10′	76° 10′	18° 10′	21° 3′	56° 45′	74° 41′	18° 8′	20° 57′	56° 38′	78° 40′	17° 44′
$1\bar{1}2$	21 51	55 52	81 21	18 10	21 16	58 27	83 1	18 8				
$\bar{1}13$	19 44	55 52	75 38	16 46	18 57	58 27	76 13	16 34	19 2	56 38	79 40	16 4
$\bar{1}\bar{1}3$	19 30	59 10	83 36	16 46	19 47	56 45	83 18	16 34				
021	43 13	0 0	43 11	0 0	42 38	0 0	43 12	0 0	44 56	0 0	45 4	0 0
$0\bar{2}1$	46 49	0 0	46 47	0 0	46 46	0 0	47 24	0 0				
110	65 8	59 10	60 38	63 23	65 53	56 45	58 4	64 4	67 47	56 38	59 23	63 57
$1\bar{1}0$	69 10	55 52	59 56	63 23	69 20	58 27	62 27	64 4				
150	78 2	17 38	19 21	63 23	79 58	17 23	19 58	64 4	81 55	16 54	18 41	63 57
$1\bar{5}0$	84 57	17 13	19 15	63 23	84 21	17 36	19 32	64 4				

Fig. 8.

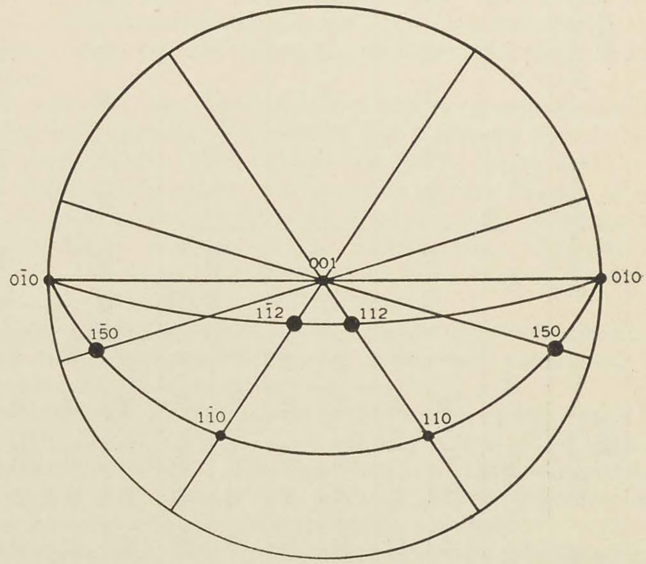

001
$0\bar{1}0$
010
$1\bar{1}2$
112
$1\bar{5}0$
150
$1\bar{1}0$
110

Fig. 9.

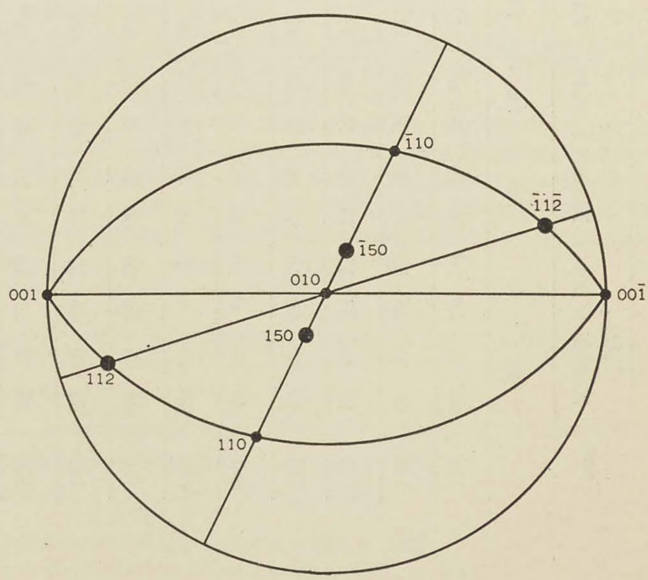

$\bar{1}10$
$\bar{1}\bar{1}\bar{2}$
$\bar{1}50$
010
001
$00\bar{1}$
150
112
110

Fig. 10.

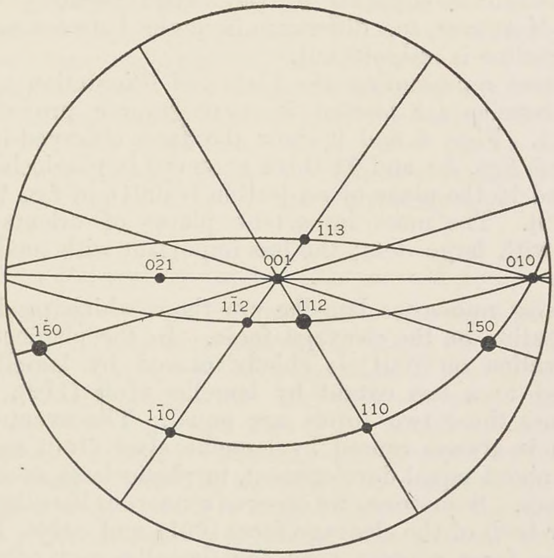
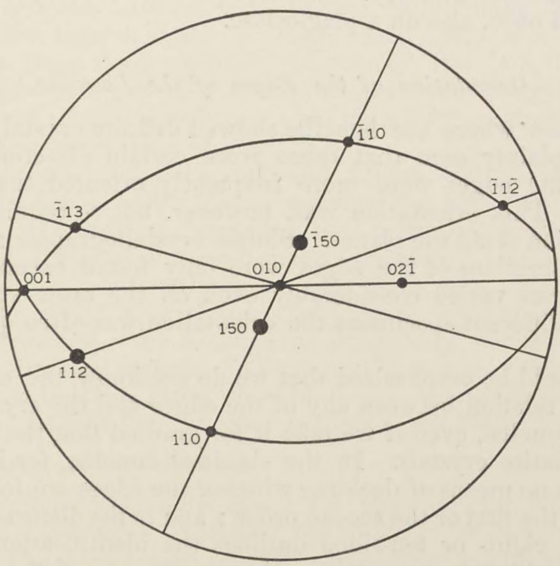

1̄13
02̄1
001
010
11̄2
112
15̄0
150
11̄0
110

Fig. 11.


1̄10
1̄12̄
1̄13
1̄50
001
010
021̄
150
112
110

of the plagioclases), but could only be referred to the apparently monoclinic elements of the entire twinned cleavage pieces. Moreover, the difference in angles between orthoclase and microcline is insignificant.

The faces representing the planes of orientation of the reflecting lamellæ are plotted in stereographic projections in figs. 8–11. Figs. 8 and 9 show the faces observed in microclines and figs. 10 and 11 those observed in plagioclases. In figs. 8 and 10 the plane of projection is (001), in figs. 9 and 11 it is (010). The most important planes of orientation are marked with large dots; the less important with smaller dots.

The most numerous lamellæ are those which produce the aventurization on the cleavage faces. In the plagioclases the aventurization on (001) is chiefly caused by lamellæ after (112) and to a less extent by lamellæ after ($1\bar{1}2$). In the microclines these two forms are equal. The aventurization on (010) is always caused by lamellæ after (150) and ($1\bar{5}0$), both of about equal development, in plagioclases as well as in microclines. Sometimes we observe numerous lamellæ parallel to one or both of the cleavage faces (001) and (010), but as a rule these faces contain very few lamellæ and often none. The same holds true for the faces (110) and ($1\bar{1}0$). Parallel to ($0\bar{2}1$) there were seen a few lamellæ in two of the plagioclase varieties examined. Lamellæ parallel to ($\bar{1}13$) were only observed once, also on a plagioclase.

Orientation of the Edges of the Lamellæ.

In cases where the lamellæ showed definite crystal outlines it was plainly seen that there were certain directions along which the edges were more frequently oriented than along others. This orientation was, however, not so regular as the orientation along the planes. Simple crystallographic relations of the directions of the edges were only found exceptionally. The angles varied considerably even on the same specimen, and on different specimens the orientation was often quite different.

It should be emphasized that we do not know the crystallographic relation between any of the edges and the crystal axes of the lamellæ, even if we take it for granted that the lamellæ are hematite crystals. In the six-sided lamellæ, for instance, we have no means of deciding whether the edges are formed by faces of the first or the second order ; and in the distorted lamellæ with eight- or ten-sided outlines the identification of the edges is still more uncertain. Moreover, many of the lamellæ have no regular outlines. We are, therefore, in general not in a

position to establish the mutual orientation between the crystal axes of the feldspar and those of the lamellæ.

In view of these facts, it was of minor interest to undertake extensive measurements of the orientation of the edges. Measurements were only made, on sections after (001) and (010) of the angles between the *a*-axis (cleavage lines) of the feldspar and the projections of the edges of the lamellæ on the respective cleavage face. These measurements can be most conveniently included in the special descriptions of the specimens.

The Properties of the Reflecting Lamellæ.

The lamellæ were too thin to be separated mechanically from the feldspar. They were, therefore, chiefly studied under the microscope in cleavage pieces or sections of the feldspar.

The different aventurine feldspars showed considerable variations as to shape and size of the lamellæ, but no distinction between different varieties could be made on the basis of other qualities. There is, therefore, no reason to consider that the lamellæ consist of more than one mineral species. In the following descriptions we refer to the general qualities of lamellæ from all the specimens examined.

Size; crystal outlines.

The smallest lamellæ were hardly visible under the microscope; the largest could be easily seen with unaided eye. Between these there were all transitions. The lamellæ of the microcline were generally smaller than those of the plagioclase, the former seldom measuring more than $0{\cdot}2^{mm}$ in diameter, the latter often measuring as much as 3^{mm}.

As observed by Scheerer* and others who studied aventurine feldspars under the microscope, the lamellæ sometimes form nearly regular hexagons but more often they show distorted, six-sided or rhomb-shaped outlines. Unsymmetrical eight- or ten-sided outlines are also often seen, and narrow rectilinear strips several times as long as wide are very common. Lamellæ with rounded or irregularly curved outlines are frequently observed. When parallel to one of the cleavage faces the lamellæ often showed more regular hexagonal or rhombic outlines than in other positions (see Plates I–III).

Interference colors; thickness.

The intense colors displayed by most of the lamellæ in reflected light were explained by Sheerer† as colors of thin films. The correctness of this explanation could be readily proved in the course of the present microscopic study. The

*Loc. cit., p. 156. †Loc. cit., p. 157.

light reflected from the opaque lamellæ was always of the same grayish color, whereas the reflections from the transparent lamellæ showed vivid colors varying with the absorption colors, that is, with the thickness of the lamellæ. It was, for instance, observed that the absorption colors of some lamellæ changed gradually from very light yellow near the edges to light brown red towards the middle. The interference colors in reflected light changed in the same lamellæ from dark gray of first order at the edges to the brilliant colors of second order near the middle.

In the thin lamellæ of yellowish or light brown tints (in transmitted light) the interference colors were not noticeably modified by the absorption of the one of the interfering rays that passed through the lamellæ. As the lamellæ became thicker, however, the influence of the absorption was more pronounced and in the deep brown red lamellæ the absorption was so strong as to suppress the interference colors. The reflected light of these lamellæ was therefore grayish like that of the opaque lamellæ.

We know that the thickness of the lamellæ is about 1/2 of the path difference between the interfering rays reflected from them. It is obvious, then, how the thickness of the thinner lamellæ that show distinct interference colors can be approximately determined. The very thinnest of the lamellæ showed the interference colors gray and white of first order and their thickness could accordingly be estimated at from 50 to 100 $\mu\mu$. Thicker lamellæ showed interference colors from yellow of first to red of second order corresponding to thickness of from 150 to 500 $\mu\mu$. The majority of lamellæ had a thickness of between 100 and 400 $\mu\mu$. In sections where the lamellæ were cut approximately perpendicular to their planes they appeared as almost invisible streaks entirely too thin to be measured with the ordinary devices of the microscope.

During the observation of the interference colors it was noticed that light reflected from lamellæ with small angles ρ never showed any detectable polarization.

Absorption colors.

The color of the reflecting lamellæ in transmitted light varied with their thickness from very light yellow and reddish brown to deep brown red or blood red.

Lamellæ forming small angles ρ with the plane of the section showed no pleochroism. Lamellæ of large angles ρ, on the other hand, appeared at first sight to be strongly pleochroic. In ordinary thin sections of the feldspar we observe the following absorption colors of such lamellæ (e. g. lamellæ parallel to (112) seen in sections after (010) or lamellæ parallel to (150) in

sections after (001)): (1) In vibration directions perpendicular to the section lines of the lamellæ—colors varying from yellow to strong brown red or blood red (depending on the thickness of the lamellæ). (2) In vibration directions parallel to the section lines of the lamellæ—colors dark brown of nearly the same tinge in all lamellæ (independent of their thickness). The change is thus apparently stronger in the thinner than in the thicker lamellæ. There is no distinct change in the quality of the colors but rather a change in the tints of the same brownish color from dark in one direction to light in the other.

This change in tints has been observed by previous authors and explained as pleochroism.* As the reflecting lamellæ have been considered hematite in tabular crystals after the base a strong pleochroism $\omega > \epsilon$ (ω dark brown, ϵ light brown) has been generally adopted as one of the characteristic qualities of hematite. A somewhat closer consideration of the observations described will, however, show that this explanation is not correct.

If the lamellæ are hematite crystals in plates after the base, those parallel to the surface of the feldspar section, or forming small angles (ρ) with the same, must show the absorption color of the vibration direction ω. According to the observations on such lamellæ their absorption colors vary between yellow and brown red. According to the observations on lamellæ of large angles ρ, on the other hand, the color of the vibration direction ω (direction parallel to the section lines of the lamellæ) should be dark brown with very little variation, whereas the colors of ϵ (or strictly a direction between ϵ and ω) should vary between yellow and brown red. In other words the absorption colors of ω in the lamellæ with small angles ρ correspond to the colors of ϵ in the lamellæ with large angles ρ. This indicates that the lamellæ have only a weak pleochroism, if any, and the dark absorption colors for vibration directions parallel to the section lines of the lamellæ of large angles ρ must be explained in the manner outlined below.

Fig. 12 shows the light rays passing through a cleavage piece $A\ B\ C\ D$ containing a lamella $E\ F\ G\ H$ of angle $\rho = 75°$. The light of the incident ray $a\ p\ h$ is supposed to be unpolarized. By the influence of the lamella the refracted and reflected rays become polarized† with the reflected ray $h\ p'\ a'$

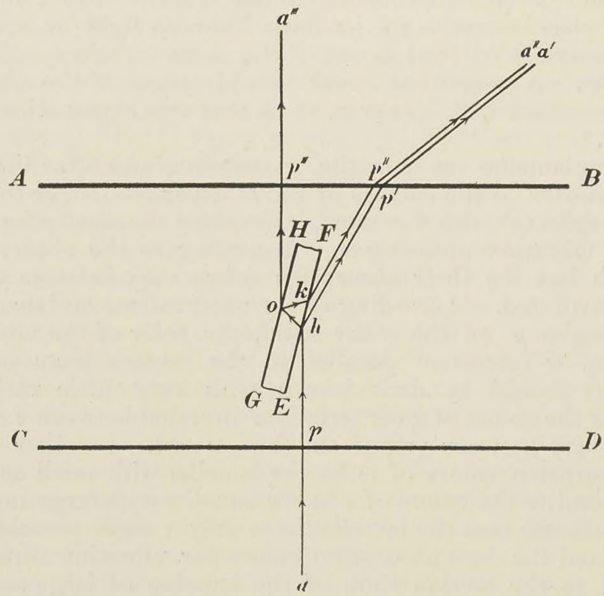
*F. Rinne, Neues Jahrb. Min., 1890, i, p. 183.

† The phenomenon of polarization by reflection and refraction is too well-known to need any explanation. It may only be recalled that the polarization, in the case of metallic substances like the lamellæ here considered, is never complete either in the reflected or in the refracted ray, but reaches a maximum for a certain (always large) angle, the main angle of incidence, and becomes insignificant for small angles of incidence. C. Försterling (Neues Jahrb. Min., B. B., xxv, 360, 1908) determined the main angle of incidence for hematite at 71°–73° for rays of medium wave lengths.

vibrating perpendicular to the plane of incidence and the transmitted ray $o\,p'''\,a'''$ vibrating in the same plane. Now if the incident ray $(a\,p)$, therefore, consists of polarized light the transmitted ray $(p'''\,a''')$ will have its maximum of intensity for the vibration direction perpendicular to the section line of the lamella and the minimum for the direction parallel to this line. This is exactly the apparent pleochroism ($\omega > \epsilon$) observed on lamellæ of large angles ρ.

The correctness of the above explanation was proved by the fact that the light reflected from lamellæ of large angles ρ

Fig. 12.

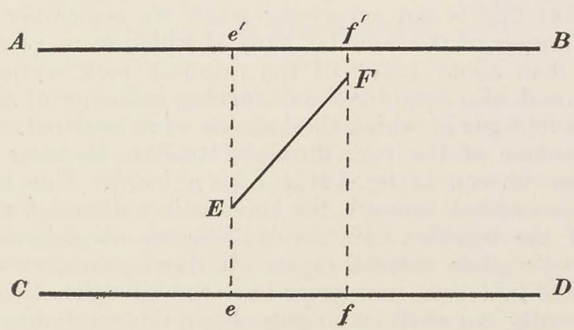


(rays $p'\,a'$, fig. 12) was found to be strongly polarized with vibration direction parallel to the section lines of the lamellæ. This was observed in a number of sections with lamellæ of angles ρ around 75°. It is then a necessary conclusion that the transmitted rays $(p'''\,a''')$ must be polarized with vibration direction perpendicular to the section lines.

The apparent pleochroism in the lamellæ of aventurine feldspars when observed at large angles ρ is not, therefore, due to any strong difference in absorption between the vibration directions ω and ϵ (if we suppose that the lamellæ consist of hematite tables), but is explained, as outlined above, by the polarization of rays when they fall on the lamellæ at the appropriate angles of incidence.

In thick sections or cleavage pieces the lamellæ of large angles ρ show in polarized light (with only one nicol) distinct interference spectra with bands parallel to the section lines. These lamellæ show the same apparent pleochroism as those in thin sections. The thicker the part of the feldspar penetrated by the lamellæ the larger is the number of bands in the spectra. In lamellæ penetrating only a thin part of the section we see, as in ordinary thin sections, no extended spectra but sometimes single, colored stripes. By rotating the microscope stage all spectra disappear in two positions at right angles with each other coinciding with the extinction directions of the feldspar between crossed nicols. This phenomenon is explained by the fact that the lamellæ (of large angles ρ) are included in the doubly refracting feldspar. In fig. 13 EF

Fig. 13.



indicates a lamella included in a feldspar section $ABCD$ at an angle ρ large enough to make the rays transmitted through it become noticeably polarized. If we use the lower nicol of the microscope the lamella will form a somewhat imperfect analyzer for the wedge-shaped part of $EFfe$ of the feldspar that lies below it. If we use the upper nicol the lamella will be polarizer for the wedge-shaped part $EFf'e'$ of the feldspar that lies above it. In either case we shall obtain an interference spectrum corresponding to the part of the feldspar wedge that lies between the lamella and the surface of the section, (the lower surface in one case, the upper in the other). It is obvious that the bands of the spectra must always be parallel to the section lines of the lamellæ. In such a stauroscopic system, where one of the nicols is replaced by lamellæ included in the section to be observed, we can not change the angles between the "nicols" and at the same time the relative position between the vibration directions of the "nicols" and those of the section at will. If the "nicols" are crossed the feldspar

section may not be in a favorable position for showing interference colors and when the feldspar is in the most favorable position the vibration directions of the "nicols" may form only a small angle with each other. Remembering this the behavior of lamellæ of large angles ρ on rotating the microscope stage presents no difficulty.

Double Refraction.

Lamellæ parallel to (or forming small angles ρ with) the sections extinguished simultaneously with the feldspar between crossed nicols. Lamellæ of large angles ρ, on the other hand, remained light when the feldspar extinguished and thus proved to be anisotropic. This is the relation to be expected if we consider the lamellæ uniaxial crystals in plates after the base. Attempts to discover axial figures in the isotropic lamellæ failed, but this is not surprising when we remember the extreme thinness of the lamellæ, most of which were actually no thicker than about 1/100 of the thinnest rock sections (see p. 370), and also consider the disturbing influence of the birefringent feldspar in which the lamellæ were enclosed.

The course of the rays through lamellæ showing double refraction is seen in fig. 12 ($a\ p\ h\ o\ p'''\ a'''$). The rays are never transmitted through the lamellæ in a direction near the plane of the lamellæ. If the lamellæ are considered to be hematite or other uniaxial crystals in basal plates, we see that the transmitted rays will never have the vibration direction ϵ. Consequently we shall in no case obtain the maximum double refraction and the path difference of the transmitted rays will depend on the thickness of the lamellæ and on their angle with the section (angle ρ).

Chemical Tests.

Scheerer* found that the originally red powder of sunstone from Tvedestrand turned white on heating with hydrochloric acid, the filtrate containing iron oxide. In the course of the present study similar tests were made on samples of various aventurine feldspars with the same result. Microscopic examinations of the powder showed that the red (pink) color was due to the presence of the thin reflecting lamellæ described and the discoloring by treatment with HCl was due to the solution of these lamellæ. These tests, therefore, show that the lamellæ of the aventurine feldspars contain iron oxide.

* Pogg. Ann., lxiv, 160, 1845.

Some Observations on Hematite.

For comparison with the reflecting lamellæ of aventurine feldspar several samples of hematite were examined as to transparency, absorption colors and pleochroism. Fine powder of the samples was imbedded in liquid Canada balsam and examined under the microscope. The degree of transparency could be estimated by selecting tabular grains lying on the flat surface, noting the color and then tilting the grains on edge (by moving the cover glass) for measurement of the thickness. The transparency varies within wide limits, some hematites being practically opaque even in the finest powder, others being transparent. For a sample of medium transparency (micaceous hematite from Montgomery County, Pa.) the following observations were made:

Absorption color	Thickness
Perfectly opaque	0·01 ^{mm}
Very dark blood red, almost opaque	0·003^{mm}
Deep blood red	0·001^{mm}

Grains of various orientation were seen in the sections. Some were parallel to the base and were perfectly isotropic; others were oriented at angles with the base and showed a strong double refraction with definite extinction directions.

If the hematite possessed a strong pleochroism this should be observed in the grains showing double refraction. In spite of careful observation, however, no distinct change in color or tint could be seen in any of the grains examined. We, therefore, conclude that the hematite has little or no pleochroism.

The absorption colors of the transparent varieties of hematite are very characteristic, blood red, brown, red, etc., according to variety and thickness and are distinctly different from those of goethite, which are much lighter and always a purer brown or yellowish.

It will be seen that these properties of hematite agree well with the corresponding properties of the reflecting lamellæ of aventurine feldspars.

Summary of the Properties of the Lamellæ.

We may now summarize the data bearing on the identification of the reflecting lamellæ.

(1) The hexagonal outlines often shown by the lamellæ, taken in connection with the optical properties which agree with uniaxial crystals in plates after the base, point to a hexagonal or trigonal symmetry.

(2) The absorption colors are the same in the lamellæ as in hematite and the lack of distinct pleochroism is also characteristic for both.

(3) Chemical tests show that the lamellæ contain iron oxide.*

(4) Thermal experiments (to be described below) show that the lamellæ do not undergo any essential change even by a prolonged heating of the aventurine feldspar at temperatures around 1050°. If the lamellæ consisted of goethite or other hydrated iron oxides we should expect a considerable change due to the decomposition of such hydrates by heating.

All these data lead to the conclusion that the reflecting lamellæ of the aventurine feldspars consist of hematite in tabular crystals after the base, as first suggested by Scheerer.

Thermal Data.

In order to obtain, if possible, some information on the stability relations between the feldspar and the hematite inclusions, a number of heating experiments were carried out.† Fresh, transparent cleavage pieces containing hematite lamellæ of various size and thickness were selected for the experiments. The outlines of the cleavage pieces and their included lamellæ were drawn with camera lucida and the colors of the different lamellæ in transmitted light were noted. After appropriate heating (in the electric resistance furnace) the cleavage pieces were removed to the air, examined under the microscope and compared with the drawings.

A brief record of the experiments is given below.

(1) Cleavage piece with numerous transparent hematite lamellæ heated for one hour at 1260° : The feldspar remained birefringent throughout with outlines sharp as before the heating; colorless; transparent, but somewhat dim. All hematite inclusions disappeared.

(2) Cleavage piece with few light-colored hematite lamellæ of sharp outlines heated for one hour at 1150° : No visible change.

(3) Same piece heated for one-half hour at 1200° : No change.

(4) Same piece heated for one-half hour at 1230° : Feldspar unchanged. Some hematite lamellæ disappeared; others became lighter and were corroded at the edges.

(5) Piece from exp. (1) heated for twenty-four hours at about 1050° : Feldspar milk white, dull, full of very fine black dust.

(6) Cleavage piece with numerous hematite lamellæ heated for one-half hour at 1235° : Feldspar birefringent; colorless; somewhat dim, but still transparent. All hematite disappeared.

*In this connection it should be noticed that lamellæ of similar qualities forming inclusions in carnallite have been analyzed separately and found to consist of Fe_2O_3 without H_2O (O. Ruff, "Kali", i, 81, 1907).

†Specimens from Aamland, Söndeled, Norway, yielded the most favorable material for these experiments on account of the freshness of the feldspar and the large size of the hematite lamellæ.

(7) Cleavage piece with some transparent and some opaque lamellæ heated for one hour at 1230° : Feldspar practically unchanged. Nearly all hematite lamellæ disappeared.

(8) Piece from exp. (7) heated for eighteen hours at about 1050° : Feldspar white, dull, only little transparent. The opaque lamellæ reappeared in the same positions and with the same outlines as before the heating (of exp. 7). They did not reflect the light as before, however, and were evidently made up of a fine aggregate of an opaque or very dark brown substance. The originally transparent lamellæ did not reappear, but at the places they had occupied a dense crowding of black dust was seen.

(9) Piece from exp. (8) heated for one hour at 1235° : The opaque lamellæ again disappeared.

(10) Same piece heated for 40 hours at about 1050° : Opaque lamellæ reappeared as in exp. (8). The feldspar opaque, full of black dust.

(11) Cleavage piece with opaque and transparent lamellæ heated for one hour at 1235° : Feldspar practically unchanged, only a little dim. Both the opaque and the transparent hematite lamellæ disappeared.

(12) Same piece heated for 45 hours at about 1050° : Feldspar dim and full of black dust. Opaque lamellæ reappeared in the same positions as before. The substance of the lamellæ now a dark aggregate as in exp. (8).

(13) Cleavage piece with opaque and transparent hematite heated for 22 days at about 1050°. The piece was examined and replaced after 1, 2, 7 and 14 days of heating. After 1 day some of the opaque lamellæ had become transparent with a deep brown color; others remained opaque. The originally transparent lamellæ were apparently unchanged. After 2 days no further change visible. After 7 and 14 days all lamellæ had become visibly lighter, some of the originally opaque lamellæ now being reddish brown, others being deep red. After 22 days the same relations persisted. The feldspar remained perfectly clear throughout (without formation of dark dust as in the cases where the heating had been first carried up to 1230°-1260°). The reflections from the lamellæ were just as intense as before the heating.

The result of these experiments may be summarized as follows:

By heating fresh cleavage pieces of aventurine feldspar at temperatures below 1230° (around 1050°) the hematite lamellæ undergo a slow change. The opaque lamellæ become more or less transparent and the transparent ones generally grow a little lighter. The change from opaque to transparent with brown red color seems to take place rather quickly, whereas

the change from darker to lighter brown red or to yellowish brown is very slow and in the lightest lamellæ a change is hardly detectible, even after a long heating. The opaque lamellæ are seldom homogeneous, but generally contain a number of irregular spots of transparent substance which shows the same colors as the entirely transparent hematite lamellæ. By a short heating these transparent parts undergo practically no change while the opaque parts become transparent and soon acquire the same color as the transparent parts so that the lamellæ become homogeneous. It seems as if the changes take place with retarded velocity and gradually cease when a certain stage is reached.

These changes might be explained as being due to a direct solution of the hematite into the feldspar (in the solid state) whereby the hematite lamellæ grew thinner and lighter. In that case we should expect the most conspicuous change in the thinnest lamellæ, some of which ought to disappear if the heating were continued for a sufficiently long time. As the experiments show, however, the thinnest lamellæ were evidently the most persistent ones, none of them disappearing and most of them undergoing no visible change even after 22 days' heating.

The change may be explained by assuming that there is a transition from a darker to a lighter modification of the hematite. The darker form is perhaps a secondary product and the original, lighter form is restored by heating. An explanation of this nature seems to account for the actual behavior of the different hematite lamellæ on heating. As the experimental data are few and only suggestive we have no basis for a detailed discussion of these problems.

The sudden disappearance of the hematite lamellæ at 1235° is most reasonably interpreted as due to a simultaneous melting of hematite together with a portion of the feldspar surrounding it; perhaps a eutectic melting or possibly a melting with a reaction between the feldspar and the hematite. Owing to the extreme thinness of the lamellæ the amount of feldspar necessary for such a melting must in any case be small. The liquid (glass) resulting from the melting will therefore occupy only very thin films in the place of the lamellæ and will escape detection under the microscope. It will look as if the lamellæ disappeared without leaving any trace, while the surrounding feldspar was unchanged and showed no sign of melting. The fact that the opaque lamellæ reappear in the same places by heating at a lower temperature proves that their substance can not have travelled far. The substance of these reappearing lamellæ is evidently different from that of the original lamellæ, and the iron oxide must therefore have undergone some change

by the melting and recrystallization. We have no means of deciding of what nature this change may have been. It is not unlikely, however, that at least a part of the hematite in melting has been reduced to magnetite.

Origin of the Hematite Lamellæ.

The investigations above described show that the aventurine feldspars must be considered oriented intergrowths between feldspar and hematite. The essential features of the intergrowths are these: The hematite crystals form exceedingly thin plates after the base and the plates are oriented parallel to some simple crystal faces of the feldspar with the edges of the hematite crystals also, in general, definitely oriented. These facts should be borne in mind when we seek an adequate explanation of the origin of the hematite lamellæ.

Of the different possible theories there are two that seem to account well for the oriented intergrowth, viz.: The theory of simultaneous crystallization suggested by Scheerer and the theory of unmixing in the solid state intimated by Johnsen (see review of literature). In discussing the origin of the hematite lamellæ in carnellite and cancrinite Johnsen points out the reasons for preferring the theory of unmixing to the theory of simultaneous crystallization in the cases of the two minerals mentioned. Similar reasons are evidently valid also for the aventurine feldspars.

It is obvious that the planes of growth of the feldspar have not, in general, coincided with the principal planes of orientation of the hematite lamellæ, as the latter planes represent extremely rare forms with the feldspars. It is highly probable, for example, that the faces 112 and 150 have never existed as crystal faces (faces of growth) in any of the specimens considered, and still they are the most important planes of orientation of the lamellæ in all aventurine feldspars. If the aventurine feldspars were considered products of simultaneous crystallization of feldspar and hematite, therefore, we would have to assume that the majority of the extremely thin hematite lamellæ during their growth formed angles with the principal faces of growth of the feldspars. This is improbable according to the common experience with crystal intergrowths, and the orientation of the hematite lamellæ thus forms a strong objection against the theory of simultaneous crystallization; a theory which otherwise would seem very reasonable.

The formation of aventurine feldspars by unmixing in the solid state may be conceived as follows: The feldspar crystals were, at the time of their separation, wholly or in part homogeneous and contained small amounts of Fe_2O_3 in solid solution,

either as hematite or as a constituent of a ferric compound. By a change in the exterior conditions prevailing at the time of formation, e. g. change in temperature, the equilibrium of the solid solution may be disturbed in such a way that Fe_2O_3 can no longer be held in solution, but must separate in individual crystals. The hematite molecules will then move towards the centers of crystallization (that is the locations of the hematite lamellæ) and feldspar molecules must move in the opposite directions. From the extreme thinness of the lamellæ we conclude that practically all these movements have taken place in the planes of orientation of the lamellæ. These planes, therefore, seem to represent definite structural planes in the feldspar, perhaps translation planes,* along which the molecules can move relatively easily. In such planes there will again be certain directions, translation directions,* of maximum mobility of the molecules, and these may account for the distortions of the hematite lamellæ. It should be noticed that some of the planes of orientation actually are important structure planes of the feldspar. Thus (001) and (010) are both cleavage planes and twinning planes. Of (110) and $(1\bar{1}0)$ one or both are cleavage planes and $(0\bar{2}1)$, is a twinning plane. It is, therefore, reasonable to consider the other planes of orientation, especially (112), $(1\bar{1}2)$, (150) and $(1\bar{5}0)$, which are observed in all aventurine feldspars, as definite structural planes, planes of translation, as suggested.

We may summarize the conclusions as to the origin of the hematite lamellæ as follows: The aventurine feldspars have been formed by unmixing of an originally homogeneous solid solution of the feldspar and hematite (or a ferric compound) in such a manner that thin hematite lamellæ have separated along structural planes (translation planes) of the feldspar.

II. DESCRIPTION OF THE SPECIMENS.

The present section contains brief descriptions, including tabulations of measurements, of all the specimens examined.

The optical properties of the feldspars were only determined to the extent necessary for an identification of the species.† Extinction angles on (001) and (010) were determined on thin sections or cleavage pieces. Refractive indices were determined on powdered material by the immersion method. As a rule only approximate determinations of the mean refractive index β were made in white light. Exceptionally the refractive

* See A Johnsen, Fortschritte der Mineralogie, vol. iii, p. 93, 1913.

† The graphical plot devised by F. E. Wright, this Journal (4), xxxvi, 540, 1913, was used in the determinations of the plagioclase.

index of the feldspar glass, produced by melting the powdered feldspar, was determined.*

In the descriptions of the hematite lamellæ only the features most characteristic for each specimen are given. Qualities like thickness, absorption colors, etc., have already been described, and as they were practically the same for all varieties they will be mentioned only exceptionally in the following descriptions.

Albite from Fisher Hill Mine, Mineville, Essex County, New York.‡

The feldspar.—The cleavage pieces were rather fresh, transparent, of a strong red color, with patches of a green substance not identified.

Extinction angle on (001) = + 3°
" " " (010) = +18°
$\beta = 1·535$
Composition: $Ab_{92}An_{8}$, a comparatively pure albite.

Polysynthetic twinning after the albite law with the one set of lamellæ comparatively broad and the other very narrow. The twinning striation on (001) was accordingly very fine.

The hematite lamellæ.—The aventurization was rather subdued, silky, produced by a great number of very small lamellæ.

Most of the lamellæ form very narrow, linear strips of maximal dimensions $0·3 \times 0·01^{mm}$; some form larger flakes with more equal diameters (maximum $0·3^{mm}$). The narrow lamellæ are generally irregularly rounded at the ends, seldom showing edges that indicate six-sided outlines. The larger flakes are sometimes approximately hexagonal, but more often irregularly rounded or tongued. Figs. 1 and 2, Pl. I show the most characteristic shape of the lamellæ.

Orientation of the lamellæ.—The goniometric measurements are given in Table 2. The planes of orientation were: (001), (010), (112), $(1\bar{1}2)$, $(0\bar{2}1)$, (150), $(1\bar{5}0)$. Most prominent were (112), (150), and $(1\bar{5}0)$, all of which contained numerous lamellæ. After (010) there were also many lamellæ, often larger than the others; after (001), $(1\bar{1}2)$ and $(0\bar{2}1)$ there were few.

The lamellæ after (112) and $(1\bar{1}2)$ were generally oriented with the projections of the elongated edges on (001) parallel to the *a*-axis. Most of these lamellæ were of the type of narrow strips described above. Other lamellæ after (112) were oriented with the projections of their elongated edges on (001)

* This method for determining plagioclase feldspars is very convenient, when a high temperature furnace is available, and probably as accurate as the best of the other optical methods. See E. S. Larsen, this Journal (4), xxviii, 265, 1909.

‡ Specimens from U. S. National Museum, No. 47773.

TABLE 2

$Ab_{92}An_8$; $n = 1{\cdot}535$

Form	Measured *i*	Measured *r*	ρ Calculated from measurements	ρ Calculated from axial ratios	ϕ Measured	ϕ Calculated from axial ratios
			Pole : Normal to 001 (ρ_P and ϕ_P)			
$1\bar{1}2$	62° 18′	10° 21′	20° 58′	20° 39′	58° 30′	59° 0′
	62 50	10 10	21 0		57 22	
112	62 43	12 14	21 40	21 49	56 30	56 3
	62 52	12 22	21 43		57 0	
$0\bar{2}1$	[1] 66 52	27 24	46 23	46 49	0 0	0 0
			Pole: Normal to 010 (ρ_M and ϕ_M)			
150	44 54	17 15	19 16	19 24	63 24	63 26
$1\bar{5}0$	45 7	16 35	19 6	19 16	64 22	

[1] $\lambda = 93° \ 24'$.

forming $+53°$ or $+63°$ with the a-axis. They formed comparatively broad strips and penetrated a number of the twinning lamellæ of the feldspar. Lamellæ after $(0\bar{2}1)$ were often oriented with their elongated edges approximately parallel to the a-axis. Most of the lamellæ after (150) and $(1\bar{5}0)$ formed narrow linear strips parallel to the c-axis; the angle between these strips and the a-axis was measured at about 63·5°. The lamellæ after (010) formed the larger flakes observed in sections after (010).

*Albite from near Media, Delaware County, Pennsylvania.**

The feldspar.—The cleavage pieces were fresh, transparent, grayish or colorless.

Extinction angle on (001) = + 1°
" " " (010) = + 16°
$\beta = 1{\cdot}535$
Composition : $Ab_{91}An_9$, albite.

The feldspar consisted of single individuals, sometimes without any twinning but generally with very narrow twinning lamellæ after the albite law inserted at regular intervals.

* Specimens from U. S. National Museum, No. 79828.

The hematite lamellæ.—Large portions of the feldspar were perfectly free from lamellæ; others contained many and showed a strong aventurization.

Most of the lamellæ were elongated, often without regular terminal edges. Sometimes they were also approximately six-sided or rhomb-shaped. They were very small, seldom more than 0·2 × 0·1^{mm}.

Orientation of the lamellæ.—The goniometric measurements are given in Table 3. The forms observed as planes of orientation were: (001), (010), (112), ($1\bar{1}2$), (150), ($1\bar{5}0$). Of these the cleavage faces (001) and (010) contained very few lamellæ, often none. The majority of lamellæ were orientated after (112), fewer after ($1\bar{1}2$), while (150) and ($1\bar{5}0$) both contained a considerable number.

Projections of the elongated edges of lamellæ after (112) on (001) formed often about +73°, sometimes −14°, with the a-axis. Other measurements did not seem to represent general orientations.

TABLE 3

$Ab_{91}An_9$; $n = 1·535$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
	47° 18′	20° 26′	20° 53′		58° 41′	
112	58 45	12 42	21 2	20° 40′	58 37	58° 57′
	59 39	11 36	20 52		58 55	
	55 5	17 57	21 56		56 24	
$1\bar{1}2$	58 39	15 12	21 49	21 48	55 49	56 6
	59 55	14 20	21 58		56 24	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	54 21	10 54	19 31	19 24	63 31	
$1\bar{5}0$	47 40	15 12	19 19	19 17	63 20	63 27
	54 45	9 49	19 16		63 58	

*Oligoclase from near Statesville, Iredell County, North Carolina.**

The feldspar.—The cleavage pieces had a grayish-brown color, and were not quite fresh, being clear in spots only.

Extinction angle on (001) = + 1/2°
" " " (010) = + 8°
$\beta = 1{\cdot}54$
Composition : $Ab_{82}An_{18}$, oligoclase.†

The cleavage pieces form polysynthetic twins after the albite law, the lamellæ of the one individual being comparatively broad, those of the other extremely narrow.

The hematite lamellæ.—In the clear spots of the feldspar there were numerous lamellæ which produced a strong aventurization. The lamellæ formed sometimes long narrow strips and sometimes distorted six-sided or rhomb-shaped plates. The largest dimensions of the strips were $0{\cdot}8 \times 0{\cdot}03^{mm}$; the plates were seldom more than $0{\cdot}3 \times 0{\cdot}1^{mm}$.

Orientation of the lamellæ.—The goniometric measurements are given in Table 4. The planes of orientation were: (001), (010), (112), $(1\bar{1}2)$, $(\bar{1}13)$, $(0\bar{2}1)$, (150), $(1\bar{5}0)$.

The most prominent set of lamellæ were parallel to (112), (150) and $(1\bar{5}0)$. After $(1\bar{1}2)$ there were fewer, and after the other planes, $(\bar{1}13)$, $(0\bar{2}1)$, (001) and (010), very few.

The projections of the long edges of lamellæ after (112) on (001) often formed about +74° with the *a*-axis. These lamellæ were elongated, strip-shaped, and traversed a great number of twinning lamellæ. Six-sided lamellæ after (112) were oriented with the projections of one of the edges on (001) forming −80° with the *a*-axis. The lamellæ after $(1\bar{1}2)$ were often elongated with the projections of the long edges on (001) approximately parallel to the *a*-axis. Lamellæ after (150) and $(1\bar{5}0)$ had distorted hexagonal or rhombic outlines. The projections of their elongated edges on (010) sometimes formed +11° with the *a*-axis.

Oligoclase from Kragerö, Norway. ‡

The feldspar.—The cleavage pieces have a strong, red color, and are usually perfectly fresh and transparent.

Extinction angle on (001) = +1°
" " " (010) = +7°
$\beta = 1{\cdot}543$
Composition : $Ab_{80}An_{20}$, oligoclase.

* Specimens from U. S. National Museum, No. 80324.

† G. F. Kunz has described orthoclase sunstone from Statesville, N. C. (History of the Gems found in North Carolina, p. 27). This may be the same sunstone as the one described here. Owing to the very fine twinning striation the feldspar might have been mistaken for orthoclase, by a macroscopic examination.

‡ Specimens from U. S. National Museum, No. 44776.

TABLE 4

$Ab_{82}An_{18}$; $n = 1{\cdot}540$

Form	Measured i	Measured r	ρ Calculated from measurements	ρ Calculated from axial ratios	ϕ Measured	ϕ Calculated from axial ratios
Pole : Normal to 001 (ρ_P and ϕ_P)						
112	46° 40′	20° 53′	20° 47′	20° 43′	58° 7′	58° 41′
	72 40	6 5	21 7		59 11	
$1\bar{1}2$	46 55	23 20	21 36	21 44	56 9	56 23
	72 32	7 48	21 42		57 8	
$\bar{1}13$	46 56	17 12	19 42	19 35	56 9	56 23
$0\bar{2}1$	[1] 62 24	31 29	46 53	46 48	0 0	0 0
	[2] 69 20	25 4	46 47		0 0	
	[3] 69 42	25 27	46 37		0 0	
Pole : Normal to 010 (ρ_M and ϕ_M)						
150	48 58	14 50	19 22	19 28	64 2	63 31
	57 7	8 50	19 24		63 51	
	58 4	8 58	19 38		63 21	
$1\bar{5}0$	48 29	13 55	19 2	19 18	63 53	
	56 48	8 32	19 14		63 38	

[1] $\lambda = 93° 37'$ [2] $\lambda = 93° 55'$ [3] $\lambda = 93° 57'$

The feldspar consisted of large, single individuals, or was sometimes composed of broad twinning lamellæ after the albite law.

The hematite lamellæ.—As the lamellæ were large and present in great numbers the aventurization was exceedingly strong, especially on (001).

Large lamellæ, measuring 2×1^{mm} or more, were numerous, but all sizes down to the very smallest were seen.

The outlines were sometimes six-sided and often rhomb-shaped or elongated. Eight-sided or quite irregular outlines were also frequently seen. (Plate II, fig. 1.)

Opaque hexagonal lamellæ were sometimes arranged in regular groups with the edges of each lamella parallel to the six-sided outlines of the groups.

Orientation of the lamellæ.—The goniometric measurements are given in Table 5. The planes of orientation were: (001), (010), (112), ($1\bar{1}2$), (150), ($1\bar{5}0$), (110).

TABLE 5

$Ab_{80}An_{20}$; $n = 1{\cdot}543$						
Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	59° 35′	12° 14′	20° 57′	20° 43′	57° 54′	58° 41′
	61 17	10 52	20 50		58 0	
			[1] 20 53		58 8	
$1\bar{1}2$	60 39	14 23	21 50	21 44	56 36	56 23
	61 20	13 8	21 34		57 2	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150			[1] 19 30	19 28	63 33	63 31
$1\bar{5}0$			[1] 19 12	19 18	63 55	

[1] Direct measurement.

Lamellæ after (110) were identified in sections after (001) and (010) by the measurements: $\phi_P = 58°$; $\phi_M = 64°$.

There were numerous lamellæ after (112) and comparatively few after ($1\bar{1}2$). After (150) and ($1\bar{5}0$) there were also many; after (001), (010), and (110) very few.

For some of the lamellæ after (112) the projections of the longest edges on (001) were parallel to the *a*-axis. For other lamellæ in the same plane the edges formed +60° or +47° with the *a*-axis.

*Oligoclase from Tvedestrand, Norway.**

The occurrence at Tvedestrand has been described by Weiby† as consisting of veins in gneiss, the essential minerals of the veins being oligoclase (sunstone) and quartz; accessory minerals, apatite, hematite, cordierite, hornblende and zircon.

* Specimens from the Mineralogical Museum of Kristiania University.
† Cited by Th. Scheerer, loc. cit., p. 154.

The feldspar.—The cleavage pieces were generally fresh and clear, of a strong, red color.

Extinction angle on (001) = +1°
" " " (010) = +3·5°
$\beta = 1{\cdot}545$
Composition : $Ab_{76}An_{24}$, oligoclase in agreement with Scheerer's analysis.*

The oligoclase was generally twinned both after the albite law and the pericline law, most of the twinning lamellæ being broad (often more than 1^{mm}). The pericline striation on (010) formed +10° with the *a*-axis. Sometimes broad cleavage pieces, without any twinning, were seen.

The hematite lamellæ.—In some specimens the hematite lamellæ were very scarce; in others they were densely crowded and of large size, producing the most brilliant aventurization. Lamellæ measuring 3×2^{mm} or even more were frequently seen. The outlines were hexagonal, rhomb-shaped or irregular.

The lamellæ after (010) were often larger and more irregularly outlined than the others.

Some few lamellæ were opaque, but most of them were transparent with the usual absorption colors.

Orientation of the lamellæ.—The determinations of the planes of orientation made by Scheerer (see p. 353) and Tertsch (see p. 354) have already been mentioned. Of these only Scheerer's have been partly confirmed by the present study (viz., the faces (001), (010) and (110)). The planes given by Tertsch, (538) and (417), could be found neither on the Tvedestrand sunstone nor on any of the other varieties examined. That Scheerer's determination of (22$\bar{1}$) as a plane of orientation is wrong was intimated by E. Reusch† and further proved by Tertsch.‡

According to my measurements (of which Table 6 contains those made with goniometer) the following forms were planes of orientation : (001), (010), (112), (1$\bar{1}$2), (150), (1$\bar{5}$0), (110). Of these (112) contained the largest number of lamellæ which cause the brilliant aventurization on (001); (1$\bar{1}$2) contained but few. After (150) and (1$\bar{5}$0) there were numerous lamellæ producing a strong aventurization on (010). Along the other faces (001), (010) and (110) there were comparatively few, none causing aventurization on the cleavage faces.

The face (110) was identified as plane of orientation by microscopic measurements : $\phi_P = 56° - 57°$; ϕ_M about 62°.

The projections on (001) of the elongated edges of lamellæ after (112) were often parallel to the *a*-axis ; some formed +72°

*Loc. cit., p. 155. † Pogg. Ann., cxvi, 396, 1862.
‡ Loc. cit., p. 248.

TABLE 6

$Ab_{78}An_{22}$; $n = 1{\cdot}545$

Form	Measured		ρ		φ	
	i	*r*	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
			Pole : Normal to 001 (ρ_P and ϕ_P)			
	45° 4′	22° 11′	20° 43′		57° 55′	
	50 32	18 2	20 46		58 17	
	54 32	15 2	20 45		58 26	
112	62 40	10 1	20 47	20° 44′	58 22	58° 34′
	67 26	7 24	20 44		57 49	
	68 40	7 3	20 49		58 24	
			[1] 20 50		58 27	
	48 30	22 31	21 42		56 48	
1$\bar{1}$2	52 16	19 21	21 35	21 42	56 7	56 18
	62 40	12 12	21 29		56 34	
	66 14	10 55	21 41		56 29	
			Pole : Normal to 010 (ρ_M and ϕ_M)			
150			[1] 19 27	19 30	63 22	
			[1] 19 40		63 16	
	45 53	17 6	19 20		63 55	63 33
1$\bar{5}$0	46 12	16 39	19 16	19 19	63 26	
			[1] 19 17		63 29	

[1] Direct measurement.

with the *a*-axis. Projections of the long edges of lamellæ after (150) and (1$\bar{5}$0) formed $-77°$ or $-84°$ with the *a*-axis. Lamellæ after (110) were generally elongated approximately parallel to (001).

*Oligoclase from Aamland, Söndeled, Norway.**

The occurrence is much like the one at Tvedestrand (according to Weiby's description of the latter). At the place where the specimens were found the prevailing gneiss included a great number of irregular pegmatite veins varying in thickness from 0·5 m. down to a few mm. The main minerals of the veins were oligoclase (sunstone), quartz and cordierite; accessory minerals, hornblende, biotite, apatite and magnetite.

The feldspar.—The oligoclase is generally very fresh, in places strong red from the hematite inclusion, sometimes grayish or colorless.

Extinction angle on (001) = $+1° - 2°$
" " " (010) = $+5°$
$\beta = 1{\cdot}545$
Refractive index of glass, $n_{Na} = 1{\cdot}507 \pm 0{\cdot}001$
Composition : $Ab_{78}An_{22}$, oligoclase, practically the same as the sunstone from Tvedestrand.

The crystals are often twinned with coarse lamellæ, after the albite and pericline laws, thus showing striation on (001) and (010). Very often, also, large pieces without twinning are observed.

The aventurization was of a variable intensity and seldom uniform over large pieces; many specimens contained no reflecting lamellæ; others contained many and showed a beautiful aventurization, not inferior to that of the best Tvedestrand specimens.

The hematite lamellæ.—The lamellæ were large as in the Tvedestrand sunstone, up to 2×3^{mm} or sometimes more. Most of them were not six-sided, but showed distinct, unsymmetrical eight or ten-sided outlines. Often they were quite irregular. Fig. 2, Pl. II, and fig. 1, Pl. III, show the characteristic shape of lamellæ in sections after (001).

Orientation of the lamellæ.—The angles of the goniometric measurements are given in Table 7. The planes of orientation were: (001), (010), (112), ($1\bar{1}2$), (150), ($1\bar{5}0$), (110), ($1\bar{1}0$). Of these (112) contained the larger number of lamellæ; ($1\bar{1}2$) only a few; (150) and ($1\bar{5}0$) contained a considerable number, the other forms very few.

The determinations of the planes (110) and ($1\bar{1}0$) were based chiefly on the microscopic measurements; for (110): $\phi_P = 57° 10'$; $\phi_M = 63° 30'$; for ($1\bar{1}0$); $\phi_P = 57° 35'$; $\phi_M = 63° 58'$.

In one case direct goniometric measurements could be made on exposed lamellæ after (110): $\rho_M = 61° 5'$; $\phi_M = 63° 55'$.

* This locality was recently discovered by Mr. Törje Törjesen, Risör. The specimens for the present description were collected by the author at the locality.

TABLE 7

$Ab_{76}An_{24}$; $n = 1{\cdot}545$						
Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole : Normal to 001 (ρ_P and ϕ_P)						
112	46° 27′	21° 17′	20° 47′	20° 44′	58° 3′	58° 34′
	49 58	18 28	20 48		57 56	
	57 26	13 13	20 47		58 19	
$1\bar{1}2$	46 27	23 9	21 22	21 42	56 57	56 18
	49 58	21 7	21 36		57 6	
	57 26	15 46	21 36		56 44	
Pole : Normal to 010 (ρ_M and ϕ_M)						
150	46 32	17 10	19 31	19 30	63 43	63 33
			[1] 19 34		63 34	
			[1] 19 28		63 50	
$1\bar{5}0$	46 34	16 40	19 22	19 19	63 17	
	47 35	16 0	19 25		63 42	
			[1] 19 20		63 29	

[1] Direct measurement.

Projections on (001) of the longer edges of lamellæ after (112) formed often $+72°$ with the a-axis. Lamellæ after (150) and ($1\bar{5}0$) were oriented with the projections of the long edges on (010), forming about $-79°$ with the a-axis.

*Labradorite from Labrador.**

The feldspar.—The cleavage pieces were fresh, of gray color and showed a beautiful labradorization on cleavage faces of (010).

Extinction angle on (001) = 5·5°
" " " (010) = 16°
$\beta = 1{\cdot}558$

*Specimens from the collection of the Geophysical Laboratory.

Composition: $Ab_{49}An_{51}$, a labradorite very near andesine.

The cleavage pieces were twinned with coarse lamellæ after the albite law.

The hematite lamellæ.—There were but few reflecting lamellæ and the aventurization was accordingly very indistinct. Most of the lamellæ were opaque, but some were transparent with the characteristic colors of hematite. They were often linear, but sometimes approximately six-sided or irregularly rounded. The largest measured 0·03^{mm} in diameter.

Orientation of the lamellæ.—The goniometric measurements are given in Table 8. The planes of orientation were: (112), (1$\bar{1}$2), (150), (1$\bar{5}$0) each with about the same number of lamellæ. The linear, strip-shaped lamellæ after (112) and (1$\bar{1}$2) were generally oriented with the projections of the long edges on (001) parallel to the *a*-axis. The long edges of lamellæ after (150) and (1$\bar{5}$0) were frequently parallel to the *c*-axis.

TABLE 8

$Ab_{49}An_{51}$; $n = 1·558$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	57° 20′	14° 12′	20° 53′	20° 51′	57° 53′	57° 58′
1$\bar{1}$2	57 14	16 24	21 33	21 34	57 23	57 10
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	55 30	11 32	19 39	19 39	63 54	63 43
	57 39	10 37	19 48		64 4	
1$\bar{5}$0	54 49	9 7	18 44	19 23	63 46	
	55 48	8 23	18 48		63 55	

It should be noticed that the plane of labradorization on (010) does not coincide with any of the planes of orientation of the aventurizing lamellæ.

*Microcline Perthite from Perth, Ontario, Canada.**

The feldspar.—The aventurine feldspar from Perth was described by Des Cloizeaux† as an orthoclase perthite. The

* Specimens from U. S. National Museum; Lea collection, No. missing.

† Ann. Chim. Phys. (5), ix, 465, 1875.

specimens examined by me consisted of microcline perthite made up of copper red microcline, and colorless albite. The microcline showed an exceedingly fine cross hatching invisible with low magnification and in places hardly detectable even with a high magnifying power of the microscope. The albite forms coarse inclusions extended approximately parallel to the *c*-axis but of very irregular cross sections.

The hematite lamellæ. — The reflecting lamellæ were restricted to the microcline, the albite never containing any. They were very small, seldom more than 0·05^{mm} in diameter, of rather regular outlines, hexagonal or rhomb-shaped, or sometimes forming linear strips.

Orientation of the lamellæ.—The goniometric measurements are stated in Table 9. The following faces were planes of orientation: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$.* After (112, $(1\bar{1}2)$, (150) and $(1\bar{5}0)$ there were numerous lamellæ causing a distinct aventurization on the cleavage faces; after (001) and (010) there were very few.

TABLE 9

Microcline: n = 1·523

<table>
<tr><th rowspan="3">Form</th><th colspan="2">Measured</th><th colspan="2">ρ</th><th colspan="2">ϕ</th></tr>
<tr><th rowspan="2">i</th><th rowspan="2">r</th><th>Calculated from measurements</th><th>Calculated from axial ratios</th><th>Measured</th><th>Calculated from axial ratios</th></tr>
<tr></tr>
<tr><td colspan="7">Pole: Normal to 001 (ρ_P and ϕ_P)</td></tr>
<tr><td rowspan="2">112</td><td>49° 2′</td><td>18° 50′</td><td>20° 59′</td><td rowspan="2">20° 57′</td><td>56° 15′</td><td rowspan="2">56° 38′</td></tr>
<tr><td>54 22</td><td>15 10</td><td>21 4</td><td>56 32</td></tr>
<tr><td colspan="7">Pole: Normal to 010 (ρ_M and ϕ_M)</td></tr>
<tr><td rowspan="2">150</td><td>40 39</td><td>17 9</td><td>18 15</td><td rowspan="2">18 41</td><td>64 27</td><td rowspan="2">63 57</td></tr>
<tr><td>56 11</td><td>6 48</td><td>18 46</td><td>64 10</td></tr>
</table>

Many of the lamellæ after (112) and $(1\bar{1}2)$ were oriented with the projection of their elongated edges on (001) approximately parallel to the *a*-axis. The elongation of the lamellæ after (150) and $(1\bar{5}0)$ was often approximately parallel to the *c*-axis.

* For the sake of comparison with the plagioclase, the positive and negative faces of forms like (112), that is 112 and $1\bar{1}2$, are put down as distinct forms, although their angles are referred to the monoclinic axes of orthoclase (see p. 364 and Table 1) and therefore are the same.

*Microcline Perthite from Mineral Hills, Middletown, Delaware County, Pennsylvania.**

The feldspar.—The aventurine feldspar from Mineral Hills was described by Des Cloizeaux first as orthoclase† and later as microcline perthite.‡

The albite inclusions are regularly extended in the direction of the *c*-axis, but have very irregular cross sections, often as much as 1^{mm} broad. On (001) we therefore see very irregular patches or bands of albite in the microcline, on (010) we see regular alternate stripes of microcline and albite approximately parallel to the *c*-axis. The microcline is greenish-gray with red spots ; under the microscope it shows the ordinary coarse cross hatching. The albite is colorless and shows the usual polysynthetic twinning after the albite law.

The hematite lamellæ.—Aventurization was only observed in the red spots of the microcline; the other parts of the microcline and the albite contained no hematite lamellæ.

The lamellæ are distorted six-sided, rhomb-shaped or form elongated strips or irregular patches. The elongated strips measure at most $0{\cdot}2 \times 0{\cdot}1^{mm}$, the more irregular lamellæ about $0{\cdot}1 \times 0{\cdot}1^{mm}$.

Orientation of the lamellæ.—The goniometric measurements are contained in Table 10. The lamellæ were oriented after the faces : (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$. Projections on (001) of elongated edges of lamellæ after (112) and $(1\bar{1}2)$ form often 20° with the *a*-axis. For other lamellæ the corresponding angle is 76°. The angle between the projections of the elongated edges of lamellæ after (150) and $(1\bar{5}0)$ on (010) and the *a*-axis is often about $-80°$.

Microcline Perthite from Näskilen, Arendal, Norway. §

The feldspar.—The cleavage pieces were rather fresh, of a brownish-gray color. The cleavage faces were often curved.

The feldspar was a microperthite with very fine, rod-shaped albite inclusions of elliptical cross sections and with the elongated direction approximately parallel to the *c*-axis. The microcline showed a very fine cross hatching.

The hematite lamellæ.—The aventurization was distinct, produced by numerous small lamellæ which never measured more than $0{\cdot}2^{mm}$ in diameter. The lamellæ often formed linear strips, but were also sometimes approximately hexagonal or rhomb-shaped.

* Specimens from U. S. National Museum ; No. 78700.
† (Orthose aventuriné) Nouv. Rech., 1867, pp. 153 and 206.
‡ Ann. Chim. Phys. (5), ix, pp. 534, 460, 463, 1876.
§ Specimens from the Mineralogical Museum of Kristiania University.

TABLE 10

Form	Measured *i*	Measured *r*	ρ Calculated from measurements	ρ Calculated from axial ratios	ϕ Measured	ϕ Calculated from axial ratios
Microcline; $n = 1{\cdot}523$						
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	51° 27′	16° 55′	20° 58′	20° 57′	56° 16′	56° 38′
	51 50	16 18	20 51		56 24	
	64 50	8 19	20 57		56 23	
	65 4	8 4	20 54		56 46	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	55 3	6 39	18 28	18 41	63 47	63 57
	55 31	6 48	18 37		63 57	
	59 13	4 46	18 44		63 20	

Orientation of the lamellæ.—Table 11 contains the goniometric measurements. The following faces were planes of orientation: (001), (010), (112), (1$\bar{1}$2), (150), (1$\bar{5}$0). Of these only (112), (1$\bar{1}$2), (150) and (1$\bar{5}$0) contained a large number of lamellæ. After (001) and (010) there were very few.

TABLE 11

Form	Measured *i*	Measured *r*	ρ Calculated from measurements	ρ Calculated from axial ratios	ϕ Measured	ϕ Calculated from axial ratios
Microcline; $n = 1{\cdot}523$						
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	57° 7′	13° 27′	21° 2′	20° 57′	57° 21′	56° 38′
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	52 27	10 0	18 57	18 41	64 38	63 57

Projections on (001) of the long edges of lamellæ after (112) and $(1\bar{1}2)$ formed frequently 15° with the *a*-axis; others were approximately parallel to the *a*-axis. Projections on (010) of the elongated edges of lamellæ after (150) and $(1\bar{5}0)$ formed often −83° with the *a*-axis.

*Microcline Perthite from Stene, Sannökedal, Norway.**

The occurrence is an ordinary granite pegmatite dike (feldspar quarry) containing microcline perthite, plagioclase (oligoclase), quartz and biotite as main minerals and a number of other minerals in smaller quantities. Different varieties of graphic granite are abundant.

The feldspar.—The perthite structure was in part coarse with visible lamellæ of albite (after 110), in part a very fine microperthite structure, with extremely thin rod-shaped inclusions of albite oriented approximately parallel to the *c*-axis. There were all transitions between these two structures, both often being found in the same little cleavage piece. The coarse perthite often formed isolated patches in the microperthite.

In the coarse perthite the microcline was developed with the ordinary cross hatching. In the microperthite the microcline structure was very fine and there was no regular cross hatching.

The hematite lamellæ.—The aventurization was restricted to the microperthitic parts of the feldspar and appeared with medium intensity about equally distinct on either of the two cleavage faces.

The lamellæ measured at most $0{\cdot}1^{mm}$ in diameter and were very variable as to shape. Some showed very regular hexagonal outlines, others were rhomb-shaped or elongated and still others perfectly irregular.

The lamellæ parallel to (001) were often collected in groups with regular hexagonal or rhomb-shaped outlines. The single lamellæ were small, mostly irregular, but sometimes hexagonal or rhomb-shaped and with the edges parallel to the outlines of the groups. The groups often measured $1-2^{mm}$ in diameter and their outlines were definitely oriented.

Orientation of the lamellæ.—The goniometric measurements are given in Table 12. The planes of orientation were the following faces: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$, (110), $(1\bar{1}0)$. Most of the lamellæ were parallel to (112), $(1\bar{1}2)$, (150) and $(1\bar{5}0)$ with about equally many after each; a considerable number were also oriented after (001), (010), (110) and $(1\bar{1}0)$.

*This locality was discovered some years ago by Mr. Peder P. Tangen, Kragerö. The specimens examined were partly obtained from the Mineralogical Museum of Kristiania University, partly collected by the author at the locality.

TABLE 12

Microcline ; $n = 1 \cdot 523$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole : Normal to 001 (ρ_P and ϕ_P)						
112	47° 40′	19° 20′	20° 47′	20° 57′	56° 19′	56° 38′
	50 17	18 14	21 5		56 42	
	51 24	16 34	20 50		56 55	
Pole : Normal to 010 (ρ_M and ϕ_M						
150	46 21	14 5	18 47	18 41	64 20	63 57
	52 5	7 59	18 13		63 50	

The form (110) (embracing 110 and $1\bar{1}0$) was established by the microscopic measurements : $\phi_P = 56{\cdot}2°$; $\phi_M = 64{\cdot}3°$.

The edges of the lamellæ after (001) were sometimes parallel to the a-axis and also occasionally parallel to the b-axis. More frequently, however, they formed oblique angles with the a-axis. Angles of 40° and 70° between the a-axis and the elongated edges of lamellæ (or the outlines of the groups of lamellæ described) were measured. Lamellæ after (010) were often oriented with one of the edges perpendicular to the a-axis more seldom forming $+50°$ with the a-axis. The lamellæ after (112), ($1\bar{1}2$), (150) and ($1\bar{5}0$) were generally so small and irregular that no definite measurements of the orientation of their edges could be made.

Miscellaneous Occurrences.

Besides the varieties described in the preceding pages, a number of other specimens were examined more superficially.* All these specimens showed a very weak aventurization and the measurements were only approximate. The results for all were that the aventurization on (001) was due to lamellæ

* In the literature we find mentioned a considerable number of occurrences besides those described or referred to in this paper. No actual descriptions of these aventurine feldspars have been given, however, and it is therefore of minor interest to list the references, most of which can be easily found in standard handbooks of mineralogy or treatises on gems. See for instance : Max Bauer, Edelsteinskunde ; G. F. Kunz, Gems and Precious Stones of North America.

oriented after (112) or ($1\bar{1}2$) and that on (010) was due to lamellæ after (150) and ($1\bar{5}0$), that is, the same as in the other specimens examined. The measurements were made with the microscope. The localities are given below, together with brief characteristics of the different specimens.

Mörefjer, Arendal, Norway.†*—Microcline, microperthite of normal structure. Hematite lamellæ few, transparent.

Rosaas, Iveland, Norway.†*—Microcline perthite partly with visible albite lamellæ, partly a microperthite. Strongest aventurization on (010). Hematite lamellæ sometimes very regular, six-sided or rhomb-shaped, transparent. Numerous lamellæ of mica after faces of (110).

*Hiltveit, Iveland, Norway.**—Microcline microperthite with very fine microcline structure and thin rod-shaped albite intergrowths. Strongest aventurization on (010). Hematite lamellæ sometimes elongated and sometimes rather regular, six-sided; transparent.

Renfrew, Canada.†—A microcline perthite of very coarse structure. Few opaque hematite lamellæ.

SUMMARY.

A number of varieties of aventurine feldspars were examined. Orientation angles of the reflecting lamellæ were measured, chiefly with the goniometer, and the properties of the lamellæ were determined under the microscope. Brief discussions of the optical problems are included in the record of these examinations.

The reflecting lamellæ are always oriented after simple crystal forms of which (112), ($1\bar{1}2$), (150) and ($1\bar{5}0$) occur as planes of orientation in all varieties, the first two causing aventurization on (001), the last two on (010). The forms (001), (010), (110) and ($1\bar{1}0$) also frequently contain reflecting lamellæ. Exceptionally ($0\bar{2}1$) and ($\bar{1}13$) are planes of orientation. The orientation of the edges of the lamellæ is evidently regular but simple crystallographic relations could not, in general, be found.

The reflecting lamellæ were determined as hematite. They vary widely from one variety to another as to shape and size, showing hexagonal, eight- or ten-sided, rhomb-shaped, strip-shaped or irregular outlines. The largest measured $3{\cdot}5^{mm}$ in one direction, the smallest were of submicroscopic size. The absorption colors are those characteristic of hematite. It was shown that the colors in reflected light are interference colors of thin films. By means of these colors the thickness of the transparent lamellæ could be approximately determined. It

* Specimens from the Mineralogical Museum of Kristiania University.

† Specimens from U. S. National Museum; No. 83218.

was found to vary between $50\mu\mu$ and $500\mu\mu$. The lamellæ were shown to possess no appreciable pleochroism. The apparent pleochroism observed in lamellæ forming large angles with the section was explained as due to the effect of polarization by reflection and refraction at the surface of the lamellæ. The appearance of interference spectra in these lamellæ was explained as due to the action of the lamellæ as polarizers or analyzers for the wedge-shaped parts of the feldspar that lie above or below them in the sections.

Thermal experiments with one of the varieties showed that the hematite lamellæ persist up to about 1235°. At this temperature they disappeared, presumably by melting together with a small part of the surrounding feldspar to thin, invisible glass films. The feldspar remained otherwise unchanged (crystallized). By heating at lower temperatures some of the lamellæ (originally opaque ones) reappeared in the same places and with the same outlines as before. By a long heating at temperatures around 1050° (of cleavage pieces not previously heated) the opaque lamellæ generally became transparent and the others became a little lighter.

The origin of the hematite lamellæ was explained as due to unmixing of an originally homogeneous feldspar which contained iron oxides in solid solution. Thin lamellæ of hematite then separated along certain structural planes of the feldspar.

In the concluding section all the specimens examined are described and the measurements tabulated.

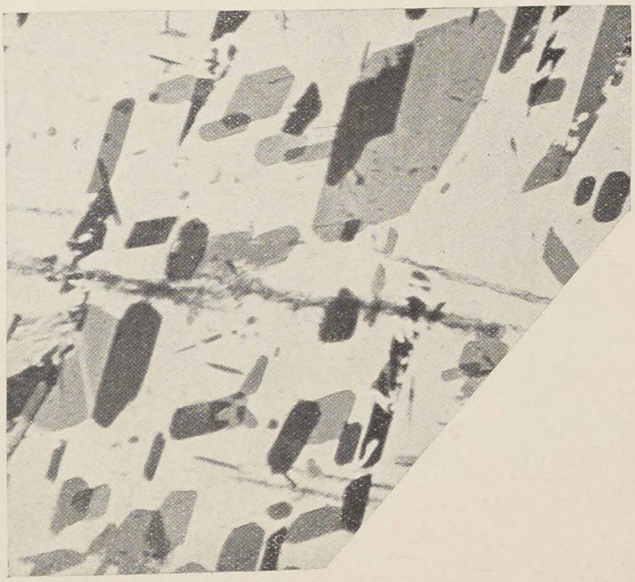
The Geophysical Laboratory of the
Carnegie Institution of Washington,
Washington, D. C., July 16, 1915.

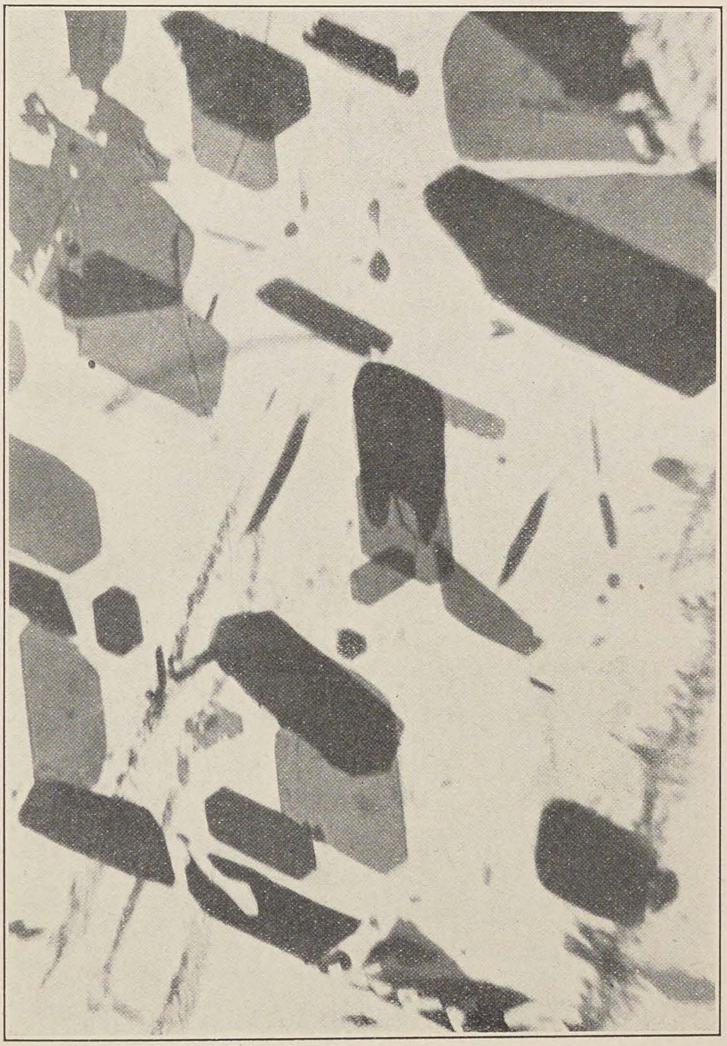
Fig. 1.

Fig. 2.

FIG. 1.

FIG. 2.





EXPLANATION OF PLATES.

PLATE I.

FIG. 1. Albite (aventurine feldspar) from Fisher Hill Mine. Thick section after (001). Ordinary light. Magnified about 30 diameters.

The vertically elongated patches are hematite lamellæ arranged parallel to (112), the long edges being projections on (001) parallel to *a*-axis. The streaks running in the direction from lower left to upper right quadrant are also hematite lamellæ parallel to (112).

FIG. 2. Albite (aventurine feldspar) from Fisher Hill Mine. Thick section after (010). Ordinary light. Magnified about 30 diameters.

The large patches are hematite lamellæ parallel to (010); horizontal streaks lamellæ parallel to ($0\bar{2}1$). Streaks running from upper left to lower right quadrant at small angle with horizontal are lamellæ parallel to (112) and ($1\bar{1}2$). Streaks from upper left to lower right at large angle with the horizontal are lamellæ parallel to (150) and ($1\bar{5}0$) with the elongated edges parallel to the *c*-axis.

PLATE II.

FIG. 1. Oligoclase (aventurine feldspar) from Kragerö. Thick section after (001). Ordinary light. Magnified about 30 diameters.

Elongated patches running from upper left to lower right quadrant are hematite lamellæ parallel to (150). Other patches are chiefly lamellæ parallel to (112).

FIG. 2. Oligoclase (aventurine feldspar) from Aamland. Thick section after (001). Ordinary light. Magnified about 30 diameters.

Chiefly hematite lamellæ parallel to (112); some parallel to ($1\bar{1}2$). The variations in the outlines of the lamellæ are distinctly seen.

PLATE III.

FIG. 1. Oligoclase (aventurine feldspar) from Aamland. Thick section after (001). Ordinary light. Magnified about 50 diameters.

Hematite lamellæ parallel to (112) showing various outlines. Near the center two lamellæ parallel to ($\bar{1}50$) running steeply from lower left to upper right.